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EDITORIAL.

THERE are at the present time about twenty-five Agricultural Colleges in Great Britain, most of which have grown up during the last ten or twelve years. These institutions are equipped with permanent laboratories and each has its own skilled staff; most of them possess an experimental farm, and all conduct field experiments with the co-operation of farmers. Many of the County Councils employ experts who lecture in agriculture and agricultural science and conduct field experiments within the area of the county. There are also a number of men who have recently taken service in India or in our Crown Colonies, and are there engaged in scientific work of an agricultural nature, but who possess no common outlet for the publication of their investigations. Now that the preliminary difficulties of organisation are passed, these workers are at liberty to turn their attention to research in Agricultural Science, and as a result a considerable amount of valuable material of a definitely scientific nature has begun to appear in College Journals and County Council Reports.

College Journals and County Council Reports have however but a restricted circulation, and are very generally neglected outside the immediate area for which they have been written, and as these reports are intended for the general reader and for circulation among farmers of all classes, scientific matter must be presented in a very untechnical form. This often results in the omission of the data necessary for

a critical appreciation of the subject; at the same time scientific papers are lost sight of amongst a mass of other work of purely local or temporary interest.

There is not in this country any general channel for the publication and discussion of scientific papers bearing on Agriculture. These papers are often too technical for publication in the journals of the societies devoted to pure science, and are not sufficiently popular for inclusion in the Journals of the Board of Agriculture or of the leading agricultural societies. The promoters of the present publication therefore consider that the time has come for the issue of a Journal devoted wholly to definitely scientific papers on agricultural subjects, containing:

(1) Original papers. The scope of the Journal will be quite catholic, it will welcome equally papers on biological subjects,—Botany, Zoology, Bacteriology, etc. and on Chemistry, Physics or Geology, provided the question bears on Agriculture. The papers must, however, represent original work; reports on the results of demonstration plots, or manurial and variety tests of an ordinary commercial character will not be admitted, nor papers dealing with general farming as distinct from agricultural science.

(2) Occasional *résumés* or critical articles on recent advances in the various branches of Agricultural Science, and notes on the more important papers appearing in British and foreign agricultural journals.

(3) Short notes from contributors who may wish to put on record exceptional cases, analyses, etc., which do not require a full paper.

(4) Articles from Indian and Colonial workers [illegible] of soil, climate and other conditions under which agricultur[illegible] carried on in tropical and semi-tropical coun[illegible]es.

(5) Reviews and discussions. It is hoped that the Journ[illegible] furnish an opportunity, lacking hitherto, for the di[illegible] in agricultural science which is being carried or[illegible]

The Journal is thus mainly intended to circulate among agricultura[l] teachers and experts, farmers and land agents having an interest in the scientific side of their profession, agricultural analysts, seedsmen, millers manure manufacturers, etc., in this and other English-speaking coun[t]ries The idea of starting such a journal was mentioned and informally dis cussed at the meeting of the Agricultural Education Association on Dec 8th, 1903, when about thirty members from various colleges, all engage[d] in agricultural work, were present, and it met with unanimous approval

The success of the agricultural sub-section at the Cambridge meeting of the British Association in 1904, also showed that ample material existed for which it was desirable to find a common and permanent means of publication.

The Journal will be issued, as material accumulates, in parts of about 100 royal 8vo. pages. Each volume will consist of four parts, the price to subscribers being 15/-. Papers for publication should be sent to T. B. Wood, M.A., University Department of Agriculture, Cambridge. Contributors will receive as an honorarium 25 off-prints of their paper free. Additional copies may be obtained at cost price if ordered when the proof is returned.

MENDEL'S LAWS OF INHERITANCE AND WHEAT BREEDING.

By R. H. BIFFEN, M.A.,

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THE investigations to be described below are the outcome of some experiments started in 1900 which had in view the improvement of English-grown wheat. The necessity of such work may not be evident to all, so at the outset I will sketch in broad outlines the state of affairs which led me to undertake the task. The fact is generally recognized that the wheats of this country are characterized by their high yields per acre and by the shapeliness of their grain. We can grow on the average over 30 bushels to the acre where the United States grow 14, Russia 10, and the Argentine 7. Yet the acreage under wheat in this country has fallen from three and a-half million acres in 1876 to one and a-half million in 1903, and we now grow approximately only one-fifth of the wheat we consume. Further than this there is good evidence to show that the quality of the grain now grown is inferior to that of twenty years ago[1]. It has been sacrificed to yield, and many of the better class varieties, such as Chiddam, Red Lammas and Rough Chaff, have been more or less driven out of the field by varieties such as Square Head and Rivet, which are capable of giving slightly larger crops of grain and straw. These inferior varieties have now to compete with wheat imported from Canada, the United States, Russia and other countries. The seriousness of the position becomes evident when one finds English wheat selling at 28*s.* 6*d.* a quarter when Manitoba Hard is selling at 35*s.*[2]

[1] Girard and Lindet, *Le Froment et sa Mouture*, Paris, 1903, p. 101.

[2] The figures are a general average—they do not refer to the abnormal prices of this season.

On searching for the reasons of this, the miller tells us that English wheat, even of the better class varieties, is lacking in "strength." We have no single variety which can be compared in this respect with the best foreign wheats. By "strength" he means the capacity of the wheat to produce a large, well-piled loaf[1]. We learn also that English wheat to be utilized at all for bread-making purposes has to be mixed with a large percentage of these strong foreign wheats. The flour of English-grown wheat, alone, will not produce a loaf which is marketable under present conditions, and until the public taste demands dull and heavy bread such wheat can only be used in mixtures.

In addition to this another complication has to be faced. Since the opening up of the wheat-growing districts of the United States and Canada, which in itself has given us an altogether new standard of strength in wheat, the milling trade has to a large extent found its way to the ports. The millers so situated grind the strong wheat brought direct to their mills by sea. The inland miller on buying foreign wheat to mix with our inferior grain has to pay railway freightage, and at present his very existence depends on the fact that he can buy English wheat relatively cheaply at his doors. If, in order to compete with the port miller, he has to use still larger quantities of foreign grain to make up for the shortcomings of our own, then prices must fall still lower or he will be driven out of the field and with him will disappear the market for home-grown wheat. The whole question then pivots on the strength of the grain we can produce. Even a slight increase in quality would go a long way to improving the position both from the farmer's and miller's point of view, for it would immediately widen the market for the home product[2]. Unfortunately we know very little as to what constitutes strength in grain. Many attribute it solely to climatic conditions and state that our problem is a hopeless one. Without discussing the matter I may point out that the work of the Home-grown Wheat Committee of the Incorporated National Association of British and Irish Millers has ruled this view out of court. We can grow strong wheat in this country, but so far the cropping power of the varieties tried has been so poor that the operation has generally resulted in loss. Realizing as I do the complications of the problem I prefer to make no definite statement as to the progress

[1] See also Maurizio, *Getreide, Mehl und Brot*, Berlin, 1903, and *Landw. Jahrb.* Bd. XXXIII. Heft II. p. 242, 1904.

[2] For further evidence see Hall, "The Quality of English Wheat," *Journ. Farmers' Club*, 1904, p. 123, and *Journ. Board of Agric.* 1904, p. 321.

we have made so far. Several years must elapse before sufficient quantities of the grain of the new varieties can be obtained to subject to the final tests of the mill and bake-house. We can but hope that among the hybrids on the experimental plots are some that will not be found wanting when these trials are made.

At the time of starting these experiments hybridizing was, to quote Lindley, writing over 50 years ago, "a game of chance played between man and plants." Looking at what literature there was dealing with the subject the chances seemed in favour of the plants. The enormous number of varieties of wheat in existence has originated, as far as we have any reliable evidence, in a similar way to the varieties of other plants. Now and then an observant person has detected a plant among the crop differing from its fellows in some character which made it worthy of further propagation. Foremost among such observers was Patrick Shirreff, who discovered many of our older varieties. They have not been built up, as is generally assumed, by a process of accumulative selection, they are rather "mutation" forms[1]. Very few, as far as we have records, have attempted to bring about improvements by cross-breeding. Thus Vilmorin has described the results of crossing together a number of the sub-species of *Triticum sativum*[2]. Rimpau in his classical memoir "Kreuzungprodukte landwirthschaftlicher Kulturpflanzen," has described the results of many years' experimenting in this direction[3]. Some few hybrids were raised in the Minnesota Wheat-breeding experiments[4]. In addition to this more scientific work some seedsmen have also attempted to raise the standard of the varieties of wheat by cross-breeding. In this country the work of the Gartons, which has resulted in the introduction of a number of fresh varieties, characterized on the whole by high-yielding properties, is the best known. Little beyond popular descriptions of their work has, however, been published. An examination of the literature existing at this date, 1900, gave one no clue as to the best methods of attacking the problem. A considerable number of crosses were therefore made indiscriminately, trusting that some few might give improvements in the required direction.

In 1901, however, the whole aspect of the problem was changed by the simultaneous discovery by three independent observers, De Vries,

[1] See De Vries, *Die Mutationstheorie*.

[2] Vilmorin, *Bull. Soc. Bot. France*, T. xxxv. p. 49, 1888; T. xxvii. p. 73, 1880.

[3] Rimpau, *Landw. Jahrb.* Bd. xx. p. 335, 1891.

[4] *Minnesota Agric. Expt. Stat.* Bulletin 62.

Correns, and Tschermak, of the work on inheritance carried out by Gregor Mendel and communicated to the Brünn Society in 1865. This was published the following year, but judging from the fact that only one reference to it is known, and that one gives slight clues as to its value, it was completely lost sight of[1]. As this remarkable paper shows, Mendel focussed his attention not on the plant as a whole but on its single characters, such as seed-shape, colour, etc., and he traces in detail the behaviour of each character in the cross-bred. Then instead of attempting to generalize from the mass of unlike forms appearing in the first generation from the cross-breds he took each individual and subjected it and its progeny to a statistical examination, again character by character. As the outcome of this series of experiments, which in themselves must in future be the model on which experiments on plant improvements are based, he was able to state that the gametes, the egg-cells and pollen grains, are pure with respect to the characters they carry. If for instance a cross is made between a round and wrinkled pea the cross-bred produces gametes which bear either the round or the wrinkled character, not a blend of the two. Postulating that an approximately equal number of pollen grains and egg-cells carry either one or the other of the characters, then certain numerical relationships observable in the progeny of the cross-breds find a simple explanation. With this clue on reading such works as Darwin's *Animals and Plants under Domestication*, Focke's *Pflanzenmischlinge*, Gärtner's *Bastarderzeugung*, one saw, though written from a totally different standpoint, that many facts till then the mysteries of the breeder, found a simple explanation. In fact to those familiar with these special problems further evidence was hardly necessary. One saw still further that many of our current theories of heredity had no real foundations, and that at the first critical test they must fail.

To agriculturists who as a class are continually in touch with the problems of heredity, both in stock and crops, exact knowledge of this kind is invaluable. In the case of our problem, for instance, if wheats behaved in the same manner as Mendel's peas, then the fixing of the chosen forms after the "breaking of the type" was going to be a simple matter requiring merely the test of a single season and not years of selection and in-breeding. If this were really the case we had prospects of, so to speak, picking out the valuable characters from different

[1] The original paper in the *Verh. naturf. Ver. in Brünn Abhandlungen*, IV. 1865, is almost unobtainable. Translations will be found in the *Journ. Hort. Soc.* 1901, Vol. XXVI. Parts 1 and 2, and in *Mendel's Principles of Heredity*, Bateson, Camb. 1902.

varieties and building up an ideal type. There were possibilities ahead the breeder had hardly dared to hope for. Fresh experiments on the same lines as those of Mendel's were accordingly planned with the object of obtaining definite knowledge as to the behaviour of all the possible characters of wheat on hybridizing. It is true that much could be deduced from Rimpau's work[1] which now became a mine of information, for from his detailed descriptions one could in many cases see clearly how certain of the characters behaved. Here and there, however, it seemed that complications occurred which would entail further investigations, so it was decided to make the experiments as complete as possible, as even confirmatory evidence has its value. During the course of this work two other papers dealing with wheat appeared. One by Spillman is of unusual interest, as it describes experiments carried out on the same lines as Mendel's though the author was at the time unaware of the fact. The results stated afford a striking confirmation of Mendel's laws[2]. The second by Tschermak again serves to confirm Spillman's results. More detailed references will be made to these in describing the behaviour of the differentiating characters later.

One older reference is not without interest now-a-days[3]. Le Couteur selected from one of his trial plots a peculiarly vigorous, red, velvet-chaffed (felted) wheat. Among the progeny were plants with red and velvet, red and smooth, white and velvet, white and smooth chaff. He counted the total number of ears, not individuals, and found 200, 21, 86, and 43 respectively of each kind[4]. His original plant was evidently a hybrid, probably a first cross as it was so vigorous, which broke up into the forms we now expect. Le Couteur concluded that this velvet-chaffed red wheat was incorrigible and put forward the following theory to account for the facts. "It might be conjectured that the original or parent ear, having been discovered in a field of mixed white corn, had been impregnated by the pollen of four different sorts of wheat, which the peculiar conformation of an ear of wheat might admit."

For a detailed study of Mendel's laws the wheats proved to be peculiarly suitable. They offer all the advantages for which Mendel originally selected peas. Thus there are a large number of varieties in

[1] *Ibid.*

[2] Spillman, *Science*, Vol. XVI. p. 794, 1902; see Hurst, *Journ. Roy. Hort. Soc.* 1903, Vol. XXVII. Part 4; Tschermak, *Zeits. Landw. Versuchs. Oesterreich*, 1901, Heft II. p. 1029.

[3] Le Couteur, *The Varieties, Properties and Classification of Wheat*, Jersey, 1837, p. 65.

[4] Compare p. 29.

cultivation (I have grown over 200) which are singularly constant; they are autogamous with rare exceptions[1]; the hybrids suffer no diminution in fertility during succeeding generations. In addition to this they have the advantage that they occupy very little space and consequently large numbers can be grown on a small plot of ground. Their chief drawback is that they require to be autumn-sown to give the best results. This leaves only a short period between harvest and seed-time to work through characters, such as those of the grain, which cannot be examined before gathering the crop.

The more important differentiating characters of wheat are as follows:—

(1) The ears are dense or lax. Ears are dense in which the spikelets are so crowded on to the rachis that they overlap one another; the internode length (the length of rachis separating each spikelet) being in such cases about 3·5 mms. Such varieties are often described as club, or club-headed wheats. A typical example is Hedgehog[2]. In lax-eared wheats the ears are generally long and in most the top of each spikelet only reaches to the base of the one immediately above it; the internode length is about 7 mms. Between these dense and lax-eared wheats is a third group with compact ears. These divisions are of course arbitrary and one finds many varieties which cannot properly be classed in either. Each variety, however, is singularly true to ear shape.

(2) The paleæ may or may not be awned. Technically they are described as bearded and beardless. Rivet[2] is an example of the former type, Golden Drop[2] of the latter.

The beardless wheats frequently bear small awns on the paleæ of the spikelets towards the apex of the ear. Such awns are usually short, not exceeding half an inch as a rule, and they cannot be confused with the awns of such a wheat as Rivet, where they are 3 or 4 inches in length and borne on every spikelet.

(3) The glumes may be glabrous or covered with fine, velvety hairs as in the well-known wheat Rough Chaff[2]. The softly hairy forms are sometimes described as "felted."

(4) *The colour of the glumes and to a less extent of the paleæ* may be red or white. "Red" includes a large number of different

[1] I have never met with a case of natural cross-fertilization, but Rimpau cites a number of undoubted examples.

[2] Figured in Vilmorin, *Les meilleurs Blés*, Paris, 1880.

shades varying from pale red to dark brown, whilst "white" is used to describe any shade from white to pale ochraceous yellows. As a rule the difference between red and white is a sharp one, but in a wet season when the chaff is apt to become discoloured it is often difficult to be sure of the colour. Each variety is quite true to its own particular shade of colour.

More rarely the colour of the chaff is grey as in Rivet wheat. This colour is, at least in my material, very variable. Some ears are dark, others light grey, but in all cases the tint is sufficiently marked to be detected with certainty.

(5) The shape of the glumes provides a number of characters used in classifying the varieties. In some of the sub-species into which *Triticum sativum* has been divided, as in *T. spelta, T. turgidum, T. durum,* the glumes have a well-marked keel running from the apex to the base. In others, such as *T. vulgare,* the sub-species which includes the majority of the varieties in general cultivation in this country, the keel is only pronounced at the apex of the glume, the base being rounded. I have described these types as "keeled" and "rounded" glumes.

(6) The grain colour is either red or white, the terms again being used to denote the range of colours already mentioned in the case of the chaff. These colours may be associated with a similar colour in the glumes. In the majority of the red-chaffed varieties the grain is also red, but a number of white-chaffed varieties with red grain are in cultivation. The converse case of red chaff and white grain is uncommon, though not impossible.

(7) The shape of the grain is frequently very characteristic, so much so that a grain merchant or miller can often identify a variety from its grain shape alone. The differences in general are difficult to describe clearly though they are readily appreciated after a little practice. In the following account grain shape is only considered in detail where very marked differences exist. In this particular case the grains are either long and triangular in section, or short and rounded.

(8) The characters of the endosperm are again difficult to describe. Those most readily recognized are the hard, translucent, and the soft, opaque types. The former type is met with in the macaroni wheats *T. durum* and *T. polonicum*; the latter is characteristic of most of our commonly cultivated varieties.

The difference is in the main associated with the total nitrogen content of the grain, the macaroni wheats containing a higher percentage than our own varieties.

It would appear also that "strength" is often associated with a hard and translucent endosperm, but further evidence is needed, for the macaroni wheats, for instance, are not "strong" wheats from a miller's point of view. In any attempts to estimate these characters it is essential to reject any ears which are not thoroughly ripened. An unripe ear of the normally soft Rivet wheat may yield hard, translucent grain.

In addition to these characteristics a number of others of less systematic importance will be considered later.

The methods of working are described in some detail below. They are the outcome of several seasons experience with this kind of work and may prove useful to others engaged in similar researches. All the plants are grown under large wire cages as a protection against the depredations of sparrows. This precaution would probably be necessary in most districts, for once sparrows begin to attack the plots they only desist when no more grain is obtainable, and the ordinary methods of scaring seem useless when one is dealing with small plots of wheat. The drawback to the use of permanently fixed wire cages is the difficulty of guaranteeing that no shed grains remain in the soil and come up with the next crop. Working the ground as soon as the crop is off and cleaning again a month later partially meets the difficulty, especially if fowls can be turned into the cages to pick up shed grain. A still more effective plan is to alternate the wheat plots with another crop. I now make use of barley for this purpose as similar experiments are in progress with it.

The actual operation of crossing wheats is a simple one and may be carried out rapidly with a little practice. After many trials I have found the following method the most satisfactory. The ear to be operated upon is selected at the stage when the anthers of the median spikelets are full-grown and beginning to show a slight tinge of yellow, indicating that they will be ripe on the following day. If the ear belongs to a dense or a compact variety alternate spikelets are removed on both sides of the rachis, preferably by tearing them off whole with a pair of forceps. The median florets of about a dozen spikelets are then removed by pressing them outwards and then pulling sharply downwards. In this way only the two outermost florets of each spikelet are allowed to remain. The remaining spikelets are then completely removed. The florets are opened by gently pressing the apex of the paleæ, or if a bearded variety is used by pressing outwards the previously cut-back awn, and the stamens are carefully removed.

Should an anther break during the operation the spikelet is cut off. Pollination is effected by immediately placing a freshly opened anther into the emasculated floret. To secure a supply of these an ear of the variety chosen as the pollen-parent is selected in which the anthers are a full yellow colour. The edges of the spikelets are trimmed off with a pair of scissors so as to open a number of the florets at the apex. The filaments of the mature stamens elongate in the course of a few minutes and push the anthers out of the opening at the apex of the paleæ. They split open and by inserting one top downwards into the emasculated floret a plentiful supply of pollen is showered on the stigma. Before making a fresh set of crosses, or in the event of a stamen from the mother-plant breaking, the forceps are sterilized by dipping them into methylated spirit. There is no necessity for removing the stamens from a floret and pollinating the following day, nor yet of carrying out the operation at an early hour in the morning. If there is any difficulty in securing the varieties in flower at the same date it is feasible to remove the stamens from the earlier variety and protect it from outside pollen. I have never examined the matter in any detail but I have frequently pollinated flowers successfully a week after the stigmas would normally have been in a receptive condition. They were then feathery and unwithered. After pollination the ears are protected by means of folded-tissue-paper bags previously waterproofed by soaking in melted paraffin wax. Numerous control experiments have shown that muslin bags are unsuitable for the purpose. An ear for instance on which 12 emasculated florets were left was covered with muslin. Each floret set a grain, pollination having been brought about by wind-borne pollen carried through the meshes of the muslin. The protecting bags may be removed a week after pollination or they may remain on the ears until the grain ripens. If the latter course is adopted the bags should be slit open at the base to allow the water to escape which accumulates, as the result of transpiration, in considerable quantities.

The artificially fertilized grains usually mature a day or two earlier than those naturally fertilized. They are frequently, but by no means always, poor and shrivelled in appearance, but they rarely fail to germinate. Working in this way it is not unusual for 90 per cent. of the artificially pollinated florets to set grain, but much depends on weather conditions. In 1903, for instance, most of the pollinating had to be done on plants sheltered from the rain by tarpaulins. Three per cent. only were successful.

The cross-bred grains are sown as early as possible and given as much space as is convenient in order to secure plentiful tillering.

In the earlier experiments the ears of the resulting plants were enclosed in paper bags or test-tubes to make sure that no extraneous pollen reached them. A series of control experiments showed that this was unnecessary and now they are simply left exposed. The most striking feature of these plants is their unusual vigour. Many have been over 7 feet high when mature, and one could as a rule detect plants resulting from accidentally self-fertilized grains by their lack of vigour when compared with their hybrid neighbours. The grain from the cross-breds is planted in ranks 2 feet long, 12 grains to each, and 8 inches apart. A space of 2 feet between each row of ranks is left as a pathway. By adopting this method the crop is readily cleaned and one can move about among the plants to examine them. Where the cross is between varieties differing only in a single pair of characters a sowing of about a hundred grains is ample to ensure all the possible types occurring among the progeny of the cross-breds. Where one is dealing with more complex cases it is well to sow as much as possible, limiting the crop only by the amount of space and time at one's disposal. Even then the crops are found to increase to such an extent with succeeding generations that much, of necessity, has to be abandoned. In cases where a considerable number of crosses has to be dealt with the entering up of the results becomes no small labour. I have found the following method satisfactory and convenient. A number is assigned to each cross in the notebook, the numbers running consecutively. The hybrid grain is sown and labelled with this number and the characters of the resulting plant noted under it. Each individual of its progeny in turn is assigned a second number, say 8—1, 8—2, 8—3, etc., and its characters are noted on squared paper. The individual numbers are placed successively in a vertical column, and opposite them the characters are noted by a mark in vertical columns reserved for each character, such as bearded, beardless, red, white, etc. In this way a record of each individual is kept with the minimum trouble and the statistical examination is simply effected by adding up the marks in each vertical column. No further numbers are as a rule necessary, as the following generation shows whether the individuals sown under these numbers will breed true or not.

Before giving a systematic description of the hybrids it may possibly simplify matters for those unfamiliar with such work if the story of one or two of the simpler cross-breds and their progeny is followed out step by

step. At the same time it may serve a useful purpose if here and there I indicate the bearing of the facts, as they are elucidated, on conceptions still current among breeders. As a simple example we may choose the case of a cross between Bearded White and Stand-up White (Carter's). The only difference between these varieties is that the former is bearded, the latter beardless. The resulting hybrid (called for convenience F_1) is as beardless as the Stand-up White (Plate I. fig. 1); there is no blending of the beardless and bearded characters resulting in a half-bearded ear. Further, the sex of the parent carrying the beardless character makes no difference, for reciprocal crosses give precisely the same result. I have tested this many times and found no exception to the rule. The fact is worth comparing with the older views on prepotency still current among breeders, who frequently treasure the belief that the female parent determines the constitution of the hybrid, whilst the male imparts such attributes as size and colour, in spite of the fact that even in pre-Mendelian days the evidence against this view was overwhelming[1]. No one can say from the appearance of a hybrid which was the male and which the female parent. It is also considered that the phylogenetically older character is the one which appears in the cross-bred. Speculations as to descent have even been based on this view. One has to admit though that our knowledge of the relative age of plant characters is in most cases very meagre, and there are a number of marked exceptions to this generalization.

Where the beardless plant is the female then the cross-bred has precisely the same general appearance (though more vigorous) as its maternal parent, and we have the well-known phenomenon of "skipping a generation"—so called because the crossing apparently has no effect in this generation, though as will be shown it has in the next. Mendel terms the character which appears in the cross-bred to the exclusion of the other a "dominant" character, and the one which is apparently lost a "recessive" character. Thus the beardless condition is dominant over the bearded. Many pairs of differentiating characters however are not sharply dominant or recessive, as will be shown later. Without thrashing old straw it may at once be noted that the phenomena of dominance are of very secondary importance[2].

The grain resulting from the self-pollination of the flowers of the cross-breds produces plants (the F_2 generation) which are either beard-

[1] Focke, *Pflanzenmischlinge*, Chap. IV. p. 469.

[2] See Weldon, *Biometrika*, I. 1902, Pt. II. and Bateson, *Mendel's Principles of Heredity*.

less or bearded, and a statistical examination shows that they occur in approximately the ratio of three of the dominant to one of the recessive forms, or $3D$ to $1R$. The plants showing the dominant character (lack of beards) are all precisely similar as far as external appearances go, but if the progeny of each individual (the F_3 generation) is examined separately it is found that only one-third of them reproduce the beardless character purely, whilst two-thirds produce both beardless and bearded offspring in the proportion of three of the former to one of the latter. The bearded plants of the F_2 generation, that is the recessives, all breed true. If we take a hundred plants at hazard from the progeny of the cross-bred (F_2) they consist not of 75 individuals with the pure dominant character and 25 with the corresponding recessive, but of 25 pure dominants, 50 similar in constitution to the cross-bred as they give the same types of offspring in the same proportions, and 25 pure recessives. We may write this generation then as $D - 2DR - R$. Further generations show that the extracted dominants represented by D and the corresponding recessives R breed true, as far as we can see, indefinitely. The following explanation of the phenomena is offered by Mendel. The two kinds of gametes of the cross-bred bear *either* the beardless *or* the bearded character, *either* D *or* R. If these are produced in approximately equal numbers, then when self-fertilization occurs the chances are that a D pollen grain may meet a D or R egg-cell, giving rise to an embryo, either with dominant characters only or a hybrid, constitutionally represented as D or as DR. Similarly an R pollen grain may give rise to R or DR embryos according as to whether it mates with an R or D egg-cell. No other combinations are possible, so the progeny would be represented by a series of individuals gametically constituted as $D - 2DR - R$. The D and R types breed true, as their gametes carry only dominant or only recessive characters, whilst when the gametes of the type represented as DR, that is the hybrid, are differentiated, then they are segregated into D's and R's, and consequently on self-fertilization the $D - 2DR - R$ series is again produced. Mendel himself tested the point as to the purity of the gametes with respect to the characters they bore by crossing hybrids with the pure dominant and recessive forms, obtaining, as would be expected, in the first case all dominant individuals [$D(D+R)$ gives D and DR], and in the second case equal numbers of dominant and recessive individuals [$R(D+R)$ gives $DR+R$][1].

[1] For further proofs see *Evolution Report of the Roy. Soc.* Pt. I.

We may now consider the results of crossing together two varieties differing in two pairs of characters, such for instance as Rough Chaff and Golden Drop. The former has a white, felted chaff, the latter a red, smooth one[1]. The hybrid (F_1) is rough and red, so that smoothness and whiteness are recessive characters, roughness and redness dominant. For the sake of convenience we may call roughness and smoothness A and a, redness and whiteness B and b. The gametes carry each of these characters pure, and their possible combinations are to be found by combining $A - 2Aa - a$ and $B - 2Bb - b$. These are AB, Ab, aB, ab, $2AaB$, $2Aab$, $2ABb$, $2aBb$, $4AaBb$. There are therefore in F_2 nine types possible, but to the sight only they appear as four, namely, rough red, rough white, smooth red, smooth white in the proportion of $9:3:3:1$. The actual numbers obtained were unusually even, being $45:16:15:5$ in a total of only 81 plants. The rough red types are represented by AB, $2AaB$, $2ABb$, $4AaBb$, since A and B are dominant over a and b respectively. The smooth red types are represented by aB and $2aBb$; the rough white types by Ab and $2Aab$, and the smooth white by ab. This accounts then for the ratio of $9:3:3:1$. The following generation (F_3) shows that the F_2 generation is composed of individuals having the constitution given above. The rough red individuals produced either all rough reds (AB), rough and smooth reds (AaB), rough reds and rough whites (ABb), or rough red, rough white, smooth red, and smooth white individuals ($AaBb$). The rough white individuals either bred true (Ab) or produced rough and smooth whites (Aab). The smooth red individuals either bred true (aB) or produced red and white smooth chaffed forms (aBb), whilst the smooth whites (ab) all bred true.

These results will serve to explain several of the difficulties of the breeder. The F_2 generation, in which the rough red, smooth red, rough white, and smooth white forms appear, represents the well-known "breaking of the type," which we now see is a rearrangement of the characters of the parents[2]. At the same time the fact is explained that the more violent the cross the greater the "variation" produced, since this implies a cross between very unlike varieties, consequently showing many pairs of differentiating characters. It has always been recognized that it is more difficult to obtain "fixed" types from such crosses than from simpler ones. The process may be illustrated by this cross as it is not a complicated one. Four types are distinguishable in the F_2

[1] They have white and red grain respectively, but for the time we will neglect this difference.

[2] In certain cases complications occur: see *Evol. Report*, Pt. I. p. 142.

generation, two of which resemble the parents, whilst two are new, namely, the rough red and the smooth white. A breeder seeking new varieties would probably select the rough chaffed red, a type which is very rare among existing wheats. This type is the commonest in this generation, being represented by nine plants out of every sixteen. Should he select any single individual it might be one of those represented as $4AaBb$, $2AaB$, $2ABb$, or AB. The chances would thus be eight to one against his selecting that represented as AB, the only one which will breed true. On the other hand, should he select promiscuously fine ears here and there, and that is the common method, the plants next season would undoubtedly consist of mixed types. Further selection on the same lines would give the same results, so that one can well believe that certain varieties of hybrid origin have taken years to fix. Where they have been got true it has been chiefly a matter of chance that DR forms have been suppressed. Should the breeder have decided to cultivate the smooth white type ab it would have bred true from the outset. Here then is the converse case of a fixture being obtained at the outset from the "variations" produced on breaking the type. It is generally believed that rigorous in-breeding will serve to fix a type, but obviously enough the in-breeding of a rough red type with a constitution represented by $AaBb$, say, can never make a fixture of it. It is true that most of its progeny would be rough and red, and that fact would be taken as demonstrating that a gradual approach to fixity of type was being obtained, but nevertheless the only fixture would be the type represented gametically as AB.

One other consideration must be noted. In F_2 the rough white and smooth red forms which appear are identical with their parents. Further they may be obtained as fixtures. Similarly from more complex crosses, when Rivet wheat was one of the parents, in the F_2 generation I have picked out a pure Rivet type and bred it true for two seasons. No one so far can distinguish this Rivet wheat from its parental form. In other words, among the progeny of cross-breds the pure parental forms occur—a fact worth noting by the breeders of pedigree stock. If one were dealing with cattle, would such extracted types be allowed a place among the *élite* of pedigree herds in the herd-book? Pedigree to a breeder implies purity of strain, which means that the individual members comprising it produce gametes of the same types only. Yet in spite of their parentage they would be as pure gametically as those boasting the lengthiest list of "recorded" ancestors.

In addition to crosses between varieties differing in two pairs of

characters, three sets of crosses between varieties differing in three pairs of characters have been investigated. The differentiating characters in one case were beardless and bearded (A and a), keeled and rounded glumes (B and b), and felted and smooth chaff (C and c). In F_2 twenty-seven gametically distinct forms are possible, eight of which are fixed, viz., ABC, ABc, AbC, Abc, aBC, aBc, abC, and abc. These fixtures have all been isolated.

An attempt was also made to follow out the progeny of a cross-bred in which four pairs of differentiating characters were united, the three pairs given above and grey and white chaff in addition. Here there should be eighty-one gametically distinct forms of which sixteen would breed true. In the F_3 generation many of the plots produced so few individuals that each type could not be recognized, for where only two or three plants resulted from a sowing of about a hundred seeds it was impossible to obtain the expected number of forms. All the possible fixtures appear to have been produced this season (1904), but in some cases the number of individuals was too small for one to be absolutely confident of the results. Such experiments involve the growing of so many small plots of plants—in this case over two hundred and seventy in the F_3 generation—that they are hardly worth the labour. It would serve no useful purpose to describe each in detail. The results have been recorded throughout, and it is sufficient to say that they are in entire conformity, where the numbers of individuals make this possible, with the results expected from a consideration of Mendel's laws.

Description of Parents.

In the following description of the varieties used in hybridizing, only the more important characteristics are noted. The species *Triticum sativum* (Lam.) has been divided into a number of sub-species, most of which are represented in the varieties described.

Rivet Wheat (syn. Cone or English wheat), *T. turgidum* (Linn.). Ears bearded, felted, compact-dense, square in section, slightly nodding; glumes grey, strongly keeled to the base; grain clear ochraceous red, slightly silky at the apex, starchy and soft; straw long (5 feet), slender, solid or nearly so in the upper internode. Leaves smooth and narrow. It was described by Linnaeus as a distinct species under the name of *T. turgidum*[1]. Now it is generally considered a sub-species of *T. sativum* (Lam.).

[1] Linnaeus, *Species Plantarum*, T. I. Pt. I. p. 478, 1797.

Red King (*T. vulgare*). Ears beardless, glabrous, lax, flattened; glumes straw-coloured, keeled above, rounded below; grain clear ochraceous red, silky at the apex; straw stout, of medium length (4 feet), hollow; leaves broad, scabrid on both surfaces, particularly the upper. The variety was introduced by the Gartons. It is of hybrid origin, Lincoln Red, Michigan Bronze and Waterloo being its parents.

Sunbrown (*T. vulgare*). Ears beardless, compact, square in section; glumes glabrous, red, keeled above, rounded below; grain red; stem stout, of medium length (4 feet), hollow; leaf rough on the upper surface.

White Monarch (*T. vulgare*). Ears beardless, medium lax, squarish in section; glumes glabrous, white, not strongly keeled; grain yellowish white; stem stout, medium length (4 feet or more), hollow; leaves scabrid above. This variety was raised by the Gartons from the following parents: Hunter's White, Victoria Red, and Rivet wheat.

Square Head's Master (*T. vulgare*). Ears beardless, compact, square in section; glumes glabrous, red, keeled above, rounded below; grain red; stem of medium length, stout. The variety is widely cultivated and may be found under many different names.

Rough Chaff (*T. vulgare*). Ears medium lax, beardless; glumes felted, yellowish-white in colour under favourable conditions, but liable to be stained during a wet season; grain amber-coloured. My plants frequently produce short awns on the paleæ of the terminal spikelets.

Golden Drop (*T. vulgare*). Ears medium lax, beardless; glumes glabrous, tinged with red; grain red.

Lammas (*T. vulgare*). Ears lax, beardless; glumes red; grain dark red.

Nursery (*T. vulgare*). Ears medium lax; chaff glabrous and red; grain red.

New Era (*T. vulgare*). Ears lax, bearded; glumes rounded below, glabrous; grain red. Of hybrid origin, introduced by the Gartons.

Stand-up White (*T. vulgare*). Ears compact, beardless; glumes rounded below, glabrous, white.

Standard Red. Similar to Square Head's Master.

"*Manitoba*" (*T. vulgare*). Manitoba wheat as received in this country is a mixture of a number of distinct varieties. The variety I have used under this name is lax, beardless; glumes white, grain red.

White Tuscan (*T. vulgare*), selected from a commercial sample which produced bearded and beardless plants. Ears lax, beardless; glumes

white, grain white. Early ripening. It has never produced bearded plants on my plots.

"*Devon*" (*T. vulgare*). Variety unidentified but possibly Talavera de Bellevue[1]. Found amongst a crop of Old Hoary in Devonshire. Ears lax, beardless; glumes and grain white.

Hedgehog Wheat (syn. Hérisson, Club wheat, Igel; *T. compactum*). Ears dense, with spreading awns; glumes brownish-grey, glabrous; grain red; straw short and slender.

Polish Wheat (syn. Goose, Diamond wheat; *T. polonicum*). Ears lax, bearded; glumes unusually long (about 20 mm. or more), straw-coloured, glabrous; grain long, translucent, amber-coloured. The plants mature rapidly.

"Minnesota" (*T. durum*), an unnamed variety grown for macaroni-making in the United States. Ears compact, bearded; glumes keeled, reddish-grey; grain amber-coloured, translucent.

In addition to these a considerable number of other varieties have been used as parents, but another season must pass before the results can be recorded. Practically all of the characters used in classifying wheats are represented in the above varieties with the exception of the brittle rachis found among the varieties of *T. spelta*. Hybrids with this as one parent are now being raised.

Description of Hybrids (F_1).

Red King ♀ × *Rivet Wheat* ♂. Ears beardless, felted, lax, flattened to about the same extent as Red King; glumes grey, strongly keeled to the base; grain red to red-brown, silky at the apex, translucent; straw very long (6—7 feet), stout, hollow. Leaves broad and scabrid above. The striking vigour of the cross-bred is well exemplified in this case. Not only was the straw of unusual length but the tillering power was equally striking. This of course is largely dependent on the amount of space available for the plant, but grown under similar conditions to the parent plants (in this case 4½ inches from plant to plant and 6 between the rows), the hybrids had at least twice as many stems as the parents. Another noticeable peculiarity was that the lower spikelets, generally some two or three in number, were sterile. This is common in many of our varieties, including Red King, but as far as my experience goes

[1] Vilmorin, *Les meilleurs Blés*.

exceptional in Rivet. The reddish-brown colour of the grain of the hybrid is probably to be attributed to lack of sunshine during the ripening period[1]. The grey colour and also the felting of the glumes was less pronounced than in the parent Rivet wheat.

The reciprocal cross Rivet wheat ♀ × Red King ♂ was also made. After a careful examination of the two sets of hybrids I could find no difference between them.

Sunbrown ♀ × *Rivet* ♂. Ears beardless, compact, the internode length the same as that of Rivet wheat; glumes grey, strongly keeled to the base; grain reddish-brown. Stem stout, long (6—7 feet), hollow; leaves scabrid above.

The ears have therefore a general resemblance to those of the cross-bred Red King × Rivet. On comparing bunches of the two though, the former have a decidedly redder tinge than the latter.

White Monarch ♀ × *Rivet* ♂. Ears beardless, medium lax, squarish in section; glumes felted, grey, strongly keeled below; grain red, but a shade paler than that of Rivet wheat; stem stout, long (6 feet and over); leaf scabrid above. As in the preceding cross-breds, the extent of the felting was variable and might readily have been overlooked in some ears. One other character, occasionally of systematic value, shown in the cross-bred is the "spreading" of the spikelets. This occurs in Rivet wheat where the flowers lie widely apart, but not in White Monarch. The same habit was detected, though not so obviously, in the cross-bred Rivet × Red King.

Square Head's Master ♀ × *White Monarch* ♂. Beardless, lax and flattened; glumes glabrous, red, rounded below; grain red, translucent; stem long (5 feet and over), stout.

The red colouring of the glumes was not quite so intense as that of Square Head's Master[1].

The reciprocal cross White Monarch ♀ × Square Head's Master ♂ gave cross-breds identical in every respect.

Red King ♀ × *Standard Red* ♂. Ears medium lax, glumes red, grain red. The laxness of the ears is slightly greater than that of Red King (Plate I. fig. 2).

Rough Chaff ♀ × *Golden Drop* ♂. Ears medium lax; glumes felted, tinged with red; grain red.

Lammas ♀ × *Manitoba* ♂. Ears lax; glumes and grain red.

Rough Chaff ♀ × *Manitoba* ♂. Ears lax; glumes felted, white; grain red.

[1] That is in 1902. Both 1902 and 1903 were peculiarly bad seasons for work of this kind. They were too wet and sunless. 1904 on the other hand was excellent.

Nursery ♀ × *Rough Chaff* ♂. Ears medium lax; glumes felted, red; grain red.

New Era ♀ × *Square Head's Master* ♂. Ears medium lax; glumes red; grain red.

Red King ♀ × *Stand-up White* ♂. Ears medium lax; glumes white; grain red.

White Tuscan ♀ × *Preston* ♂. *Ears lax, beardless; chaff tinged with red; grain red.*

White Tuscan ♀ × *Manitoba* ♂. Ears lax; chaff white; grain red.

Devon ♀ × *Hedgehog Wheat* ♂. *Ears compact, beardless; glumes brown; grain red and translucent; straw long (up to 5 feet), stout.* In general appearance the hybrid resembles the variety Thickset or Hickling (Plate I. fig. 3).

Polish ♀ × *Rivet Wheat* ♂. Ears lax, bearded; glumes felted, varying in colour from pale grey to isabelline white, long but shorter than those of Polish wheat; grains long, but shorter than those of Polish wheat, red, translucent. The plants mature slowly.

The reciprocal cross-bred Rivet ♀ × Polish wheat ♂ was identical in appearance (Plate I. fig. 4).

The grain from selected ears of the cross-breds was sown early, as much of it was poor and shrivelled, partly owing to attacks of rust, partly to the lack of sunshine. Its germinating power was however satisfactory. Even in the seedling stage it became evident that "splitting" was occurring, for among the hybrids with Rivet wheat as one parent there were obviously different types of leaf shape and leaf colour. The vigour of the plants was also very variable, and by the time of ripening many of the weaker individuals had been crowded out of existence by their more vigorous neighbours. By then some of the plants were standing 7 feet high, while some few on the other hand were barely 18 inches. This dwarfing was not due to over-crowding, for several of these lowly plants grew on the open margin of the plots, and in one small plot containing three of them each had over a foot of clear space either side. The dwarf individuals only occurred on plots with a Rivet parentage. The period of maturation was again very variable, some few plants ripening their grain early in August, but the majority not until late in the month or the beginning of September. Taking the plants of this generation (F_2) as a whole they were not characterized by great fertility as in the preceding generation. About 10 per cent. of them were altogether sterile, and many produced only a small quantity of grain. There were a few noteworthy exceptions though; one plant, for instance, produced 1,280 grains.

DETAILED ACCOUNT OF THE VARIOUS CHARACTERS AND THEIR BEHAVIOUR IN F_1 AND F_2.

BEARDLESS × BEARDED.

The beardless condition is a dominant, the bearded a recessive character. This result has already been obtained by numerous workers. Rimpau's crosses between Red German bearded wheat and Kessingland, Rivet wheat and Saxon Red wheat, and White Spelt and Red German bearded wheat, were all beardless in the first generation[1].

Further, Spillman[2] and Tschermak[3] have obtained similar results in the first generation and also shown that in the second generation the beardless and bearded plants occur in the usual Mendelian ratio of 3 : 1.

One peculiar case has to be recorded. Vilmorin[4] crossed *Triticum polonicum* and Pétanielle blanche (a white Rivet-like wheat), both of which are bearded, and obtained a beardless hybrid. In this case then the combination of two characters which are recessive appeared to give a dominant. It seems probable though that the hybrid was really bearded, but the awns were shed on ripening. This phenomenon is not unusual and I have met with it in the very similar cross-bred Polish × Rivet wheat.

The following hybrids were without exception beardless: Rivet × Red King, Sunbrown × Rivet, White Monarch × Rivet, Rivet × Red King, Bearded White × Stand-up White, Devon × Hedgehog. The next generation (F_2) consisted of beardless and bearded plants. Out of one total of 364 plants 91 were bearded and 273 beardless; in another case 60 were bearded and 27 beardless; in another 34 and 11; in another 58 and 16; in another 15 and 4. Taking all the plots together this gives 440 beardless to 149 bearded, or a ratio of 2·95 : 1, a sufficiently near approximation to the expected ratio of 3 : 1.

Among this number were a few plants with the short terminal awns, up to half an inch in length. As this occurs in the awnless parents such plants were reckoned with the beardless forms. In the succeeding generation F_3 the bearded forms, *i.e.* the recessives, without exception bred true, whilst the beardless forms either bred true, *i.e.* pure dominants, or gave a mixture of bearded and beardless plants. A statistical

[1] Rimpau, *loc. cit.* [2] *Science*, 1902, Vol. XVI. p. 794.

[3] Tschermak, *loc. cit.*

[4] Vilmorin, *Bull. Soc. Bot. France*, T. XXXV. p. 49, 1888. See also T. XXVII. p. 73 and p. 356, 1880.

examination of two of such plots from Rivet × Red King gave a total of 94 beardless to 32 bearded plants. Among a total number of 163 plots from this cross (F_3) 88 produced a mixed offspring, corresponding to the $2DR$ of $D - 2DR - R$ in F_2. The numbers are a little wide of the expected ratio 2 : 1, but owing to the small number of plants which survived the winter (1903) one could not always be certain that a plot with say only half-a-dozen beardless plants represented a pure extracted dominant or a hybrid, for with so small a number the bearded (recessive) forms might well have been missing.

Velvet Chaff × Glabrous Chaff.

The felted or velvety character is dominant, the glabrous recessive.

This is deducible from Rimpau's crosses between Rivet and Square Head wheat, Mainstay and Square Head, Early Red American and Mainstay, and from a number of natural crosses which he has recorded. Vilmorin has obtained similar results in the case of a Spelt crossed with Blé à duvet (Rough Chaff), and Spillman and Tschermak have again proved that in the second generation three velvet chaffed wheats are produced to each smooth chaffed plant.

Nevertheless some difficulties occur on a further examination of this pair of characters. Thus Rimpau's cross between Saxon wheat (glabrous) and Rivet wheat (velvet) is quoted by de Vries [1] as an example of a character usually recessive being dominant.

On referring to the original the hybrid is found to be described as "vollig der Vaterpflanze" (*i.e.* Saxon Red). No special mention is made of any particular character and further no hairs can be distinguished in the figure of it (Taf. XIII. Nr. 13). Rimpau also makes no mention of the felted character in the hybrids resulting from the union of Rivet and Red German Bearded wheat, though in the case of Red American × Mainstay he describes the felting as being slight but distinct.

In the following hybrids the glumes were felted:—Rivet × Red King, Sunbrown × Rivet, White Monarch × Rivet, Red King × Rivet, Rough Chaff × Golden Drop, Rough Chaff × Nursery, Manitoba × Rough Chaff, Polish × Rivet. On comparing them though there was found to be this difference. In those with Rivet parentage the felting was very variable in extent, but where Rough Chaff was one parent

[1] De Vries, *Mutationstheorie*, Band II. p. 40.

it was constant and as fully marked as in that parent. None of the Rivet cross-breds were as strongly felted as the Rivet itself, and many would have been classed as glabrous unless they had been examined under a lens.

Perfectly glabrous ears did not occur. The gradation from felted ears to glabrous was so gradual that it was impossible to divide the series into strongly and slightly felted individuals.

An examination of my stock of Rivet wheat showed that this particular character was a singularly constant one, so that no explanation could be found by assuming parental variation.

The case then is obviously different from any of those met with by Mendel in peas. If the characters are represented as *I* and *II*, and the hybrid by a, a diagram such as:—

a

I ———————————————— II

would represent the character *I* as being regularly dominant, while such a case as the above would have to be represented as:—

$a \quad a^1 \quad a^2 \quad a^3 \quad a^4 \quad a^5 \quad a^6 \quad a^7 \quad a^8$

I ———————————————— II

the individuals nearest *I* being strongly hairy.

I am inclined to think that Rimpau's hybrids would be included in this second group, and then it would be quite intelligible that the slight hairiness, say of a^7 or a^8, should have escaped notice, particularly as at that time no special attention had been called to the necessity of examining the hybrids character by character.

In the next generation (F_2) felted and glabrous individuals occur:—Rough Chaff × Golden Drop, 63 felted to 23 glabrous; Manitoba × Rough Chaff, 373 : 140; Rough Chaff × Nursery, 262 : 79. The totals for these three plots therefore give the ratio of 698 : 242, or approximately 3 : 1.

In the cases where Rivet wheat was one parent the following figures were obtained:—Rivet × White Monarch, 23 : 17; Sunbrown × Rivet, 49 : 22; Red King × Rivet, 151 : 77; or a total ratio of 223 : 116[1].

The separation was variable where Rivet wheat was the felted parent, for plants occurred with ears which were strongly felted

[1] The figures for Polish × Rivet and its reciprocal have not been ascertained yet.

whilst others were almost glabrous, together with all possible intermediates between these extremes. The number of individuals examined, namely 339, should be sufficient to have given a reliable estimate of the proportions of felted and smooth individuals. The ratio obtained (223 : 116) is strongly suggestive of a ratio of 2 : 1.

However, a further examination of the next generation (F_3) pointed conclusively to the fact that the segregation of this pair of characters occurred according to the usual 3 : 1 ratio. Thus among the plots of Rivet × Red King (F_3) were some with the following ratios of felted to smooth:—66 : 22, 38 : 13, 8 : 2, 18 : 9, 84 : 29, or a total of 214 : 75.

It is possible that an explanation of this wide departure from the normal ratio in the first generation from the Rivet hybrids may be found in a partial shedding of the hairs on the glumes during ripening. The matter is being further investigated.

Grey and White Chaff.

The grey colour of the glumes and paleæ is shown to be a dominant character in the descriptions of the hybrids with Rivet wheat. From the literature already in existence it was evident that difficulties would be met with on examining this particular pair of characters. Thus Rimpau's crosses between Rivet wheat and Red German Bearded and Square Head gave plants which were somewhat like Rivet wheat in colour, *i.e.* grey was dominant, but the cross between Rivet wheat and Saxon Red (p. 24) would again form an exception as it gave plants resembling Saxon Red.

I have examined over two hundred plants from the series (F_1) mentioned above, and have without exception been able to detect grey colouring, though in some cases it was only slightly developed.

In extreme cases it was almost as intense as in Rivet wheat, whilst in many on the other hand the general coloration of the ears much resembled that of the other parent. In the latter case the grey colouring was for the most part confined to the longitudinal strips in the glumes where it appears to be most intense in the Rivet wheat. The crosses with *Triticum polonicum* afford a typical case of this, for at first sight they resemble that parent in colour very markedly but on closer inspection the grey patches are visible.

Were the grey colour inherited in full intensity the hybrids with

red and white chaffed parents should show precisely the same grey-coloured chaff in each case, but taking them in separate bundles one could say with certainty which was descended from a red-chaffed and which was descended from a white-chaffed wheat.

It is evident then that a pre-Mendelian description of such hybrids would frequently omit any mention of so poorly marked a character, but the more detailed examinations, character by character, which are now necessary would at once detect it. Rimpau's description of the hybrid between Rivet wheat and Saxon Red cannot then be considered as an exceptional case showing the grey colouring as a recessive character. It rather refers to a hybrid diagrammatically represented as a^6 in a series where I represents the irregularly dominant grey colour (cf. p. 25).

The explanation of this irregularity is probably to be found in the fact that the grey-colouring is a peculiarly variable character in the parent Rivet wheat.

In the second generation grey and white chaff separate out in the usual proportions. Thus from the plants produced from Red King × Rivet (F_2) 161 were grey and 56 white, or approximately three grey plants to one white (a number of discoloured individuals being excluded as doubtful). The most striking point with regard to this particular pair of characters in this generation was their extraordinary variability, the coloration ranging from almost black to isabelline white, a far greater range than could be found in the original Rivet wheat. In spite of this the cases where one could not be certain of the grey character were merely those due to accidental discoloration. The extremely dark plants often had the greater part of the upper internode coloured with purple.

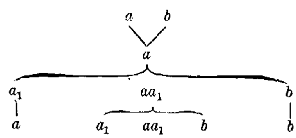
It seems probable that this increased range of variation, which also occurs with other characters besides the pair under consideration, will be of some use in the building-up of new wheats where it becomes necessary to strengthen or weaken them in any particular way. Fixed forms of these extreme dark and extreme light plants have been obtained in F_3.

In the first generation from the cross-bred Rivet × Polish wheat the grey coloration is practically wanting, and looking at the plots casually one would have said that a case of failure to segregate had occurred. A more detailed examination has shown that many of the glumes are faintly marked with grey, but no single plant out of some 2000 was as dark in colour as even a light ear of the parent Rivet.

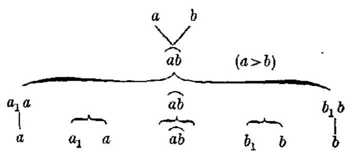
No figures can be given at present to show the relative frequency of the grey and white forms, as the examination of this particular set of plants has had to be deferred.

RED AND WHITE CHAFF.

The fact that the red colour of the glumes is a dominant and the white a recessive character is evident from a considerable number of cases already known. A typical example is found in a cross made by Vilmorin between a white spelt and a red wheat which produced (F_1) a red spelt-like wheat. Spillman's experiments also point to dominance of red over white, but both Rimpau and Tschermak have described examples in which a mixing of the parental colours occurred. In the following hybrids the ears were red or reddish: Red King × Square Head's Master, Red King × Standard Red, White Monarch × Square Head's Master and its reciprocal, Rough Chaff × Golden Drop, Lammas × Manitoba, Devon × Hedgehog (brown). Where the full red colour was not developed the result is almost certainly to be explained by the lack of sunshine in 1902 and 1903, for in all the cross-breds grown in 1904 the colour was as clear and as well developed as in the parents. At the same time the possibility is not excluded that we again have to deal with irregular dominance similar to that shown by the grey colour. The difficulty is recognized by Tschermak, who concludes that this pair of characters does not show simple dominance and recessiveness. If Mendel's scheme is represented as



he represents the behaviour of this colour pair as:



the hybrid showing characters belonging to each parent, and sub-

sequently splitting in a more complex fashion than those with strictly Mendelian characters.

To test this point several hundred plants of the F_2 generation of each of these red cross-breds were raised. In 1903 the season proved unfavourable and finally only those of Rough Chaff × Golden Drop were harvested. The ears from these plants were then compared with Golden Drop (the red parent) and Rough Chaff (the white parent) and, in spite of the fact that the former would be considered a very light coloured type of a red wheat, there was no difficulty in separating them out into 64 red and 21 white plants, that is, the usual 3 : 1 ratio. At the same time the red colour of the ears frequently differed from that of Golden Drop, sometimes being darker, sometimes lighter, but this variation was so frequently found among ears from one and the same plant that it was impossible to group them, as individuals, into plants showing the pure red and plants showing the intermediate colour.

One further test of the accuracy of this counting was possible by comparing the distribution of the red and white among the velvet and smooth chaffed wheats. Neglecting five plants which were poorly developed and stained, the remaining 81 were composed of 5 smooth white, 15 velvet white, 16 smooth red, and 45 velvet red individuals, that is, the expected distribution of:

$$9VR \quad 3VW \quad 3SR \quad 1SW.$$

In 1904, under far more favourable conditions, the F_2 generation of Lammas and Manitoba was raised. It consisted of 329 red individuals to 115 white. The red coloration was practically constant, and no intermediates occurred. It would seem therefore that the dominance of red over white is pure in these cases.

RED AND WHITE GRAIN.

The red colouring matter of the grain is confined to the testa of the seed and shows through the thin, transparent ovary wall. The white wheats do not possess this colouring matter, so red and white grains form an easily recognizable pair of characters. Imperfect ripening tends rather to exaggerate the difference, for the red grains are then usually liver-coloured, whilst the white grains become only a shade yellower. In the hybrid plants (F_1) of Rough Chaff × Golden Drop and Rivet × Polish wheat the grain was invariably of a clear red colour, so

perfectly distinct from the amber colour (so-called "white") of Rough Chaff and Polish wheat, that a single grain could be picked out from a sample of them. In the next generation (F_2) the plants of Rough Chaff × Golden Drop were separated into red- and white-grained by matching them against the grain of their parents, Golden Drop and Rough Chaff. Six doubtful plants were neglected, leaving a total of 80; 60 of which had grain matching that of Golden Drop, 20 that of Rough Chaff. As a further test 200 ears taken from separate plants of Manitoba × Rough Chaff (F_2) were examined. They gave 154 red to 46 white-grained forms. Segregation into red and white grain also occurs in Rivet × Polish wheat (F_2) but no statistics are as yet available. There are also indications that dark red is dominant over light red, for the progeny of the cross-bred Lammas × Manitoba, the former of which has very dark grain, consists of dark and light grained individuals. The evidence therefore points to the fact that red is dominant over white and the splitting in F_2 is pure.

KEELED AND ROUNDED GLUMES.

This pair of differentiating characters occurs in the crosses between Rivet wheat with Red King, White Monarch and Sunbrown. In all cases the hybrids (F_1) showed the keeling of the glumes in undiminished intensity. In the following generation (F_2) keeled and rounded individuals occurred in the ratio of 171 : 58, 37 : 17, and 30 : 10. In F_3 one plot only, of Rivet × Sunbrown, was examined for this pair of characters. It contained 84 keeled and 26 rounded individuals. The totals are therefore 322 keeled to 111 rounded or a ratio of 3 : 1.

LAX AND DENSE EARS.

In practically all the varieties I have made use of there has been some slight difference in the length of the internodes between the spikelets, though the crosses between Rivet and Polish, and Devon and Hedgehog wheat are the only ones which afford a really well marked difference between the parents in this respect. Rimpau's[1] cross between early Red American and Square Head wheat, and Vilmorin's[2] between Polish wheat and Pétanielle blanche show that the lax type is dominant over the dense. In one set of Spillman's[3] crosses the length of the

[1] *loc. cit.* [2] *loc. cit.* [3] *loc. cit.*

hybrid ear is intermediate between that of the parents, and in the following generation lax, intermediate, and dense ears occur in the ratio of 1 : 2 : 1.

As a typical case we may take the cross between Square Head's Master and Red King with average internode lengths of 3·2 and 4·6 mms. respectively. The hybrid ears were laxer than the lax parent, averaging 4·8 mms. (Plate I. fig. 2).

The increased length of the hybrid ears is probably simply a correlation with the increased height of the hybrid plants, it being a general rule that dense ears are associated with a short straw, and lax ears with a long straw.

In the second generation (F_2) at the first sight it appeared as if the splitting into lax and dense ears was most irregular, owing to the fact that many of the plants produced long, dense ears, or long, lax ears, or the corresponding short forms. It was found impossible to sort the ears into the two types by inspection only, so a typical ear from each of one hundred individuals was measured, the number of spikelets counted and the average length of the internodes estimated. This gave a result of 78 lax to 22 dense individuals, 4·6 mms. and over being considered as lax and measurements below that as dense. The figures are suggestive of the three to one ratio though they depart rather too widely from it.

Among the lax-eared individuals the exaggeration of the character was frequently met with, 24 plants having an average internode length of over 4·6 mms., while one ear showed as high a figure as 5·0 mms. No ears were found with shorter internodes than the dense parent, though from inspection only it appeared that this would be the case.

In the case of Rivet wheat (3·6 mms.) × Polish wheat (6·6 mms.) the hybrid internodes averaged 5·8 mms. The F_2 generation consisted of plants with internode lengths ranging from 3·1 to 6·8 mms. A large number were measured by Mr W. L. Balls and the figures obtained point to a segregation into dense, intermediate, and lax in the ratio of 130 : 362 : 179 or (?) 1 : 2 : 1. The results stated are provisional, for the matter is still being investigated. The first generation of Devon × Hedgehog wheat has produced ears which are intermediate between their parents in respect to the lax and dense characters. It resembles therefore the hybrid described by Spillman which produced the lax, intermediate and dense ears in F_2[1]. The F_2 generation of this has still to be grown.

[1] Spillman, *loc. cit.*

Hollow and Solid Straw.

The cultivated varieties of *T. vulgare* show in all that I have examined a hollow straw while Rivet wheat (*T. turgidum*) has a thin straw, especially below the ear, which is practically filled with pith—a fact well known to Jethro Tull, who describes it as "having its straw full of pith like a rush." The two types are so distinct that one often hears the Rivet straw described as "goose-necked" by agriculturists.

When wheats showing the two types are crossed the resultant hybrid always has a thick, hollow stem similar to that of the *T. vulgare* variety. Rimpau's illustrations do not show this particular pair of characters as the ears are cut off too closely, and I can find no reference to it in the literature I have consulted, though from the technical point of view straw structure is almost as important as yield of grain.

That the hollow type is dominant over the solid is however evident enough from an examination of the Rivet series of crosses.

In the following generation (F_2) splitting occurs and a number of very different types of straws occur, some being thick and solid, slender and solid, thick and hollow, thin and hollow, ribbed and ribless, rough and smooth. These were sorted out into hollow and solid individuals, with the result that 170 of the former were found to 56 of the latter. This pair of characters then splits in the usual Mendelian ratio.

A further examination of the straws gave a sufficient reason for the multitude of forms occurring in this generation, it being found that numbers of other characteristics could be detected.

These are best seen in transverse sections of the stems, taken for the sake of uniformity from the middle of the uppermost internode in each case. The two types are afforded by Rivet wheat and Red King. In the former the outline of the stem is strongly ridged, the ridges being formed by massive girders of sclerenchyma running out from the large innermost bundles. The parenchymatous tissue of the pith either completely or almost completely fills the innermost part of the sections. In Red King the stem outline is nearly circular, its regularity being only broken by slight undulations formed for the most part by sclerenchyma girders from the smaller vascular bundles. Girders are also formed from the larger innermost vascular bundles. The epidermis, particularly on the ridges, bears numbers of short, stiff bristles. The parenchyma of the pith forms a thin layer only, the stem being hollow. The sclerenchyma girders are far less massive

throughout than those of Rivet wheat, and those from the innermost ring of bundles are no more developed than those from the smaller exterior bundles. Sections of the stem of the hybrid generation (F_1) are more strongly ridged than those of Red King owing to the greater development of sclerenchymatous tissue, the pith is only slightly developed, and the short, stiff epidermal hairs, absent in Rivet wheat, are present on the ridges.

The development of the girders is not, however, as marked as in Rivet wheat. Reciprocal crosses, and crosses between Rivet wheat and Sunbrown, show the same characters. From this it would appear that a hollow pith and solid pith, bristly and smooth epidermis, angular and circular stem sections, massive and slight sclerenchyma girders are differentiating pairs of characters, the first mentioned in each case being dominant. The last pair belongs to the "more or less" order, and the question might be raised as to whether the increased amount of sclerenchyma is not to be correlated with the increased vigour of the hybrids.

The numerous types of stem are, therefore, the expected result of shuffling a number of pairs of characters together. An anatomical examination of a number of chosen stems resulted in finding the majority of the predictable types, but the task of grouping the whole set statistically has still to be undertaken. The fact that the one pair so examined splits in a Mendelian ratio makes it probable that the remainder of these anatomical characteristics do so also.

The same types of splitting have also been observed among the heterozygotes (DR's) in F_3 and a number of the more promising forms have been saved to breed from later.

ROUGH AND SMOOTH FOLIAGE.

From the descriptions of the hybrids it is clear that the rough type of leaf is dominant over smooth. Sections of the leaves of Rivet wheat, the smooth parent, show that the upper surface in particular is covered with slender hairs. Similar hairs, though relatively less abundantly, occur on the leaves of Sunbrown, White Monarch, and Red King, but here they are mixed with short, stiff bristles, similar to those occurring on the stem. The presence of these bristles accounts for the roughness of their foliage. The foliage of the F_1 generation of Rivet, crossed with either Red King, Sunbrown, or White Monarch, invariably bore short,

stiff bristles interspersed with the longer silky hairs, showing that here again their presence is a dominant character, their absence a recessive.

Broad and Narrow Leaf-shapes.

Where a wheat exhibiting markedly broad foliage is crossed with one possessing narrow leaves the hybrid bears the broad type of leaf, as is shown in the single cross of Red King and Rivet wheat, and its reciprocal. In the next generation (F_2) broad and narrow foliage occurs together with leaves difficult to place definitely in either class. The numerical relation of these classes was investigated in one case with the result that 57 individuals were grouped as broad, 67 as narrow, and 110 were neither one nor the other.

Assuming that these 110 individuals were normal, and that the foliage was fully developed—the plants were not crowded together—the figures suggest a ratio of 1 : 2 : 1.

Probably the leaf colour affords yet another pair of characters, some varieties being a deep bluish-green others a glaucous green. Indications of this have been seen in several cases, but the matter has not been investigated.

Time of Ripening (Late and Early).

The hybrids between Polish wheat and Rivet wheat afforded an example of this particular pair of characters. Polish wheat is tender, and to avoid danger from frosts it has to be sown in this country about the middle of March, it then grows rapidly, rushes through its flowering and ripening stages, and may be harvested by the first week in August Rivet wheat, on the contrary, is hardy, and when autumn sown is usually about the last of the commonly grown varieties in this country to ripen. On my plots during 1903 it did not ripen until the third week in August. Definite dates are difficult to give, because in thinly sown plots the plants tiller considerably, and the smaller ears of the side branches may be a fortnight later in ripening than the ears of the main branches.

The grains obtained as the result of the crosses made in 1902 were sown on March 15th in order to avoid the risk of damage by frost, as there was the possibility of tenderness being a dominant character, and

a few grains of Polish and Rivet wheat were put in alongside to serve as controls. The Polish wheat showed signs of ripening early in August, and by the third week of the month the ears, even on the side tillers, were thoroughly matured. The hybrid plants, however, pushed their ears through the sheaths from five to seven days later, and produced no ripe grain until September 17th. The side tillers were not harvested until a month later, and even then they were not thoroughly ripened. The late sown Rivet wheat ripened the main ears on the plants late in September, but the ears of the side tillers were not ripe when the plots were finally cleared away on October 20th. The time of ripening for the hybrids is a little earlier than that of the late parent Rivet wheat.

In the next generation F_2 (sown Feb. 26th) all the plants flowered simultaneously; the ears pushed through the sheaths on June 11th, and the stamens were ripe on June 18th. The Polish wheat sown on the same date also flowered at this period, but the Rivet wheat was twelve days later. The first signs of ripening were noticed on July 10th. By July 30th many plants were ripe, others were almost ripe, others dead green. At this date the Polish wheat was ripe, whilst the Rivet was quite green.

A statistical examination was then made, the following being the criteria used for grouping the plants:—Ripe, glumes and straw yellow, grain hard; half-ripe, awns yellow, glumes beginning to turn yellow, straw yellowish-green, grain soft; unripe, green throughout. The results were 103 ripe, 210 half-ripe, 100 unripe. A second plot[1] gave 84 ripe, 171 half-ripe, 79 unripe. The figures clearly indicate a ratio of 1 : 2 : 1.

On August 3rd a small plot of 74 individuals, the survivors of 200 autumn-sown grains, contained 56 ripened plants and 18 unripe, so that an examination at this stage would have pointed to the fact that early ripening was a dominant character. The true state of affairs is of course shown by the other statistics. It is worth noting that the time of ripening was in no way correlated with the habits of the plants. Individuals resembling Polish wheat were either early, late, or intermediate in their ripening periods, and the same is true for the Rivet-like individuals.

Probably similar results could have been obtained with the other Rivet hybrids, though there was not so marked a difference in the ripening

[1] W. L. B.

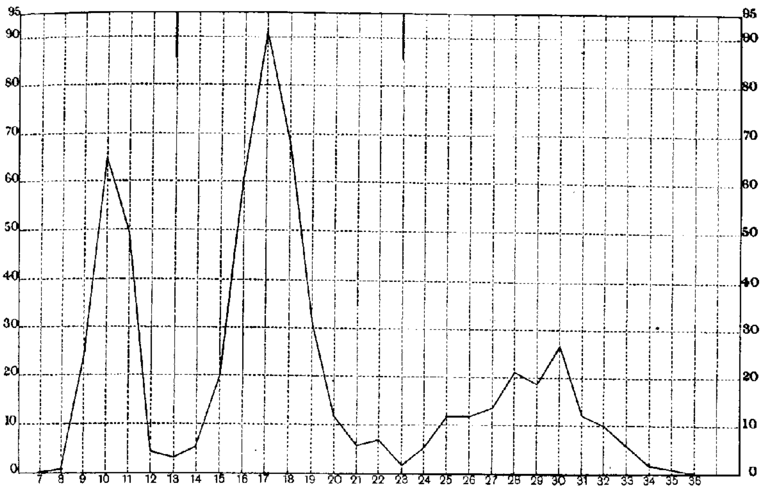
periods. In both the F_2 and F_3 generations of these hybrids great differences were observed between individuals in this respect. This season (1904), for instance, ripe ears were gathered on August 7th from Rivet × Red King (F_3), whilst other plants were not fully ripe at the end of the month. This points to an intensification of characters similar to that already described in the case of the grey colouring of the glumes. The case is of interest as it affords an example of a pair of constitutional as opposed to morphological characters.

Long and Short Glumes.

These characters are represented in the cross between Polish and Rivet wheat and its reciprocal. A somewhat similar cross was made by Vilmorin between Polish wheat and Pétanielle blanche, a variety of *T. durum*. The cross-bred (F_1) produced glumes which were intermediate in length between those of the parents. The same result occurred with my cross-breds, the glumes again being of an intermediate size in both cases. The average glume length of 21 plants was 17 mms., that of the parents 28 and 9 mms. respectively. The peculiar loose appearance of the ears of Polish wheat caused by the glumes standing away from the rachis in an irregular manner was not represented in the cross-breds. Their more compact manner of growth resulted in square ears more like those of Rivet wheat (Plate I. fig. 4).

The F_2 generation at first sight seemed to consist of individuals with glume lengths varying from one extreme to the other. The long, intermediate, and short types were obviously present, but one continually hesitated as to whether any particular individuals should be classed as short, or intermediate or long. The glume lengths of a number of plants were therefore measured with direct-reading callipers, the measurements being taken from the base to the shoulder of the glume. In each case the third glume from the base of the ear was taken to be the standard. This was considered necessary as the glumes of the spikelets towards the apex of the ear are smaller than those towards the base, and preliminary measurements pointed to this as the best position for giving representative results. The glume lengths ranged from 8 to 35 mms. These were plotted on squared paper, the lengths along the base line, the number of individuals vertically, with the result that the curve so obtained was found to be sharply divided into three distinct portions. The three separate curves corresponded with the small, the intermediate, and the large glumes. On

counting the number of plants represented in each curve they were found to be 149, 304, and 142. A second series of measurements on the reciprocals gave the numbers 205, 432, 188. The figures are a fair approximation to the ratio of 1 : 2 : 1, showing that on the separation



Glume length curve of 595 individuals of Rivet × Polish wheat, F_2.

of the gametes of the hybrid into those carrying the long and short characters where long meets long we have the long type of glume, similarly where short meets short the short type, and where long meets short, as in the original operation of artificially crossing, the intermediate type is produced.

The curves are of interest from another point of view. That corresponding with the small glumed type is steep and shows a range of 5 mms. (from 8—13 mms.), that corresponding to the large type is flattened with a range of 12 mms. (from 23—35 mms.), whilst the intermediate curve is compounded of the flat and steep curves with a range of 10 mms. (from 13—23 mms.). The steep and flat curves correspond broadly with those of the parents. Curves plotted with the glume lengths of Rivet wheat are steep, those with the glume length of Polish wheat flat, for in this sub-species the glume length varies over a considerable range. No detailed figures are given here as the matter is one which is worth further investigation.

Long and Short Grains.

These characters have also been examined in the Polish × Rivet wheat hybrids and their offspring. In my material the grain lengths are 10·1 and 7·2 mms. respectively. Before describing the results it is necessary to have a clear idea of the structure of a grain of wheat. It must be realized that we are dealing with a fruit in which the carpel wall is fused with the testa of the seed proper in such a manner that the seed cannot be separated from it. The study of the grain characters is further complicated by the fact that the endosperm of a grain resulting from an artificial cross is as much a hybrid as the embryo itself, for this endosperm arises from the definitive nucleus which has previously been fertilized by one of the two generative nuclei of the pollen tube. The grain resulting from a cross is therefore partly hybrid (the endosperm and embryo) and partly a portion of the female parent (the testa and carpel wall), or to put the matter crudely the endosperm is a generation ahead of the grain coats[1]. Presumably the shape of the grain is determined by the endosperm.

The hybrid grains of the reciprocal crosses were, as is usually the case, slightly shrivelled, but the shapes and colours corresponded with those of the female parents, those borne on the Polish parent being longer and more slender in shape than those on the Rivet parent and also paler in colour. In the following generation (F_1 of the plants) the grains produced by the reciprocal crosses were identical in appearance. They were relatively broader than those of Polish wheat and longer than those of Rivet wheat—the length being on the average 9·0 mms. Such grains could properly be described as intermediate between those of the parents. There was no segregation into the long and short types in this generation (Plate I. fig. 5).

The generation raised from these grains (F_2 of the plants, F_3 of the endosperm) consisted of individuals with short, intermediate, and long grains. The distribution of these will have to be considered later when I have found an opportunity to work through the whole crop. It may however be stated that the small grains only occur among the plants with small glumes, the large grains among the plants with large glumes[2].

[1] No actual proof of this has been given in the case of wheat, but Guignard has shown that this double fertilization occurs in maize.

[2] Some 200 individuals examined.

Similar cases though not sufficiently distinct for accurate estimation have occurred in the crosses between Rivet and Red King and a variety of *T. durum*.

This failure to segregate in the expected generation appears to afford a parallel to the case of the indent peas quoted by Tschermak and again investigated by Bateson[1]. No satisfactory explanation of the phenomena can be afforded, but when one takes into account the distribution of the different types of grain mentioned above it seems clear that the maternal plant characters—in this case of size of the glumes—in some way directly influence the seed characters in each generation.

HARD AND SOFT ENDOSPERMS.

I have used these terms in describing endosperm characters which really represent relatively high and low total nitrogen contents respectively, as the texture in itself affords a ready approximate method of judging this particular character. I recognize that the method is not an infallible one, but it is the best we have at present. The hard endosperms are usually translucent and glutenous, the soft ones opaque and starchy. Polish and Rivet wheat are examples of these two types. The endosperm of the grains produced as the actual result of the cross was hard in both sets of crosses. No stress can be laid on this fact though, as the ripening was not normal, the grains being shrivelled, and shrivelled grain is generally of this texture. The grain of the next generation (F_1 plants with F_2 endosperm) was all hard, whilst that of the parents ripened alongside as controls was hard in the case of Polish and soft in the case of Rivet wheat. Here and there a grain which was partially opaque (starchy) in patches occurred, but these were altogether confined to late-ripening side tillers. The number of such grains was not determined, but it was certainly less than 1 per cent. Their occurrence may safely be neglected, for grain from the side tillers of Polish wheat showed the same appearance. The expected segregation into hard and soft grain did not occur in this generation, but it occurs in the F_3 generation (F_2 of the plants), enough of which has been examined for me to be sure of this fact, but not enough to afford any statistics as to the numerical relationships existing between the two classes. A preliminary examination of the nitrogen contents as

[1] Presidential Address, Zoological Section, British Association Meeting, 1904.

determined by Kjeldahl's method, has given the following results. Polish wheat 2·3—2·5 % N.; Rivet wheat 1·8 % N.; hybrids 2·45, 2·3, 2·16, 2·04, 2·01, 2·0, 1·99, 1·94, 1·84, 1·83, 1·81, and 1·72. The figures are too small to base any conclusions on, but they seem to point to a segregation into high, intermediate, and low nitrogen contents. That segregation does occur is illustrated by the following fact. I sent two samples of the grain from an F_2 generation of a cross, in which these particular characters were not so distinct as in the case under consideration, to Mr A. E. Humphries, of Coxe's Lock Mill, for his opinion on them. Their parentage was not stated, yet he came to the conclusion that the grains were samples, not from cross-breds, but from the two original parents which he named[1]. Further evidence hardly seems necessary. 200 ears taken at random gave 152 hard to 48 soft-endospermed forms, or a ratio of 3 : 1.

Immunity and Susceptibility to the Attacks of Yellow Rust.

It is generally recognized that certain varieties of wheat are far more susceptible to the attacks of rust (as a rule *Puccinia glumarum*) than others, and from time to time suggestions have been made that more immune varieties should be sought for in order to minimize the losses annually caused by the attacks of this fungus[2]. Our knowledge of what determines immunity to the attacks of fungi is so slight that practically nothing has so far been achieved in this direction. One had no ideas of the lines on which such investigations should proceed. Some years of experience with numerous varieties not only of wheats but of barleys, swedes and potatoes have convinced me that these varieties can be grouped into classes according to their capacity for resisting various diseases, and that broadly speaking the grouping for one season holds with reasonable accuracy for other seasons, whether the disease is epidemic or only slight[3]. This being the case it follows that some varieties inherit a constitution making them capable of withstanding the attacks of certain fungi, others one making them susceptible. Other

[1] The difference between these types of endosperm is too subtle for me to attempt to describe. They are the slight differences which can only be appreciated by those who continually handle grain.

[2] As far back as 1815, Thomas Andrew Knight suggested that varieties proof against the mildew (or rust) should be raised. *Pamphleteer*, Vol. VI. p. 402.

[3] Cf. Eriksson, *Die Getreideroste*.

workers have come to the same conclusions. Thus Farrer states that the susceptibility to rust is hereditary in wheat[1]. If this is the case it is important to know what would happen when immune and susceptible varieties are crossed. To test this point Michigan Bronze was crossed with Rivet wheat and *vice versâ*. This latter wheat is as a rule fairly immune to yellow rust, and I used a strain selected two years previously (in 1899) which was peculiarly so. Michigan Bronze is probably the most susceptible wheat to yellow rust in existence. So badly are the plants attacked on my plots that I can hardly obtain enough grain each season to sow again.

Six plants of this parentage were raised. They were at first strong and vigorous, but by the middle of June (1902) the whole of their leaf surface was covered with rust pustules, which spread until the glumes and even the awns were orange with it. There was nothing to choose between the reciprocals in this respect either. On harvesting, these plants produced three grains which failed to germinate—a fact which will indicate the severity of the attack. A second series of crosses, those between Red King and Rivet wheat and the reciprocal, were examined from the same point of view. Red King is again very susceptible to yellow rust, possibly because Michigan Bronze is one of its parents. These hybrids were also badly rusted and indistinguishable in this respect from Red King growing alongside. They yielded, however, some 300 grains from which 260 plants were raised in 1903.

The season was favourable for such work, the rust epidemic being even worse than in the preceding year. It appeared as early as March 16th, but only spread slowly until the last week in May. By June 15th the epidemic was judged to be at its climax and the extent and percentage of disease were observed. The result was 78 plants almost free from disease, 118 showing a few pustules only, and 64 badly diseased. The extent of infection though increased steadily, and a second count on June 29th reduced the number of relatively immune plants to 64, whilst the remaining 195 were infected, for the most part badly. Now the ratio 64 : 195 seems to be too close an approximation to the ratio 1 : 3 to be a mere accident, and taken in conjunction with the fact that the F_1 generation was so badly attacked it is fair proof that susceptibility and immunity are definite Mendelian characters, the former being the dominant one.

This experiment has an important bearing on the "mycoplasm"

[1] Farrer, *Agric. Gazette of New South Wales*, 1889, Vol. IX. p. 131.

hypothesis put forward by Eriksson to account for certain facts with regard to epidemics of rust which need not be described in detail[1].

The main point of the hypothesis is that "a latent germ of disease is inherited from the parent plant," the parent being the *mother plant*. For a time this germ exists in "une symbiose intime" with the host plant, then under certain more or less defined external conditions the fungus protoplasm develops, giving rise to the parasitic rust.

This hypothesis is difficult to accept and still more difficult to disprove[2]. It was not until Eriksson actually demonstrated the "mycoplasm" and mycelium arising from it that this became possible. Then an elaborate histological examination carried out by Marshall Ward[3] showed clearly that what Eriksson had taken to be the developing fungus protoplasm consisted in reality of the haustoria pushed into the host-cells by the intercellular mycelium of the rust. Eriksson working in collaboration with Tischler[4] after further research admits the identity of his first "mycoplasm" with the haustoria, but now states that the granular contents of certain otherwise normal cells in the leaf of the wheat are the symbiotic blend of fungus and host-protoplasm[5].

Assuming then the truth of this hypothesis, and excluding for the time being all chance of external infection, the plants are immune if they inherit no "latent germs," and susceptible if they do so. Where external infection is possible the fact is not altered that immune plants inherit none since no disease occurs. If then A is immune and B is susceptible, A ♀ × B ♂ should be immune and B ♀ × A ♂ should be susceptible, since the "latent germs" are transmissible by the maternal parent[5]. The reciprocal crosses where Rivet wheat is the immune parent and Michigan Bronze or Red King the susceptible parent show however that this is not the case, for A ♀ × B ♂ and B ♀ × A ♂ are both highly susceptible. Here again then the "mycoplasm" hypothesis does not conform with the facts observed, but breaks down precisely where the student of heredity would expect it to. To bring it into conformity with our present knowledge of the subject it would have to be assumed that the "latent germs" can be handed on by the male parent as well, that is by way of the generative nuclei!

[1] Eriksson, *Ann. d. Sc. Nat.* T. XIV. p. 107, 1901.

[2] For negative evidence see Klebahn, *Die wirtswechselnden Röstpilze*, p. 79, 1904.

[3] Marshall Ward, *Proc. Roy. Soc.* Vol. LXXI. p. 353, 1903, and *Phil. Trans.* Vol. CXCVI. p. 29, 1903.

[4] Eriksson, *Comptes Rendus*, 1903. Cf. *Archiv für Botanik*, Band I, p. 143, 1903.

[5] *Ibid.* and *Rev. gén. de Bot.* 1898, T. x. p. 44.

This conception of immunity and susceptibility as definite constitutional characters throws some light on other aspects of the immunity problem. The most important of these is its bearing on the attempts to correlate immunity with morphological characters. By way of an example, one not infrequently finds it stated that thick-cuticled wheats or potatoes are more immune than those with thin cuticles. Where serious attempts have been made to trace any connection between such characters and immunity, as in the case of Marshall Ward's work on the Bromes[1], none whatever can be found, and one is driven to conclude that the differences are intraprotoplasmic. Now certain well-marked differences between the leaf characters of the varieties experimented with have already been pointed out, and at first sight it might well have been that immunity was dependent on one of these[2]. Nevertheless among the progeny of the hybrids (the F_2 generation) it was found that immunity by no means depended on any of these characters, leaves of the Red King type being as free from disease as those of the parent Rivet, whilst leaves of the Rivet type were as frequently badly rusted. The immunity simply depended on the luck of the shuffle.

The F_3 generation has in its turn given results which confirm those of the preceding generation. From the 260 plants composing it 163 plots were raised in 1904. One hundred and eighty-five were sown originally, but the conditions at seed-time were far from suitable and 21 failed entirely. Many plots only contained a few plants. At the end of May it became obvious that the relatively immune plants of the former season (*i.e.* the recessives) were breeding true in this respect, for each plot stood out sharply as a green patch among the orange plots of badly rusted individuals (dominants and hybrids). On counting out the plots 49 were relatively free from rust, and 114 were either rusty or contained an excess of rusty individuals. The separation into plots representing the extracted dominants and the mixed individuals was not attempted owing to the small number of plants on some of the plots, which would probably have led to confusion. The figures are very wide of the expected ratio, but the error is on the right side, for it is only reasonable to assume that the mortality would be greatest among the progeny of the most susceptible individuals in F_2 which in consequence of disease had produced seed of poor vitality. The failures should then be reckoned

[1] Marshall Ward, *Anns. Bot.* Vol. XVI. p. 233, 1902.

[2] Cf. Hartig's *Diseases of Trees*, Engl. edit. 1894, p. 171, where the cultivation of a woolly-leafed willow hybrid is recommended in place of its glabrous-leafed parent in districts where *Melampsora hartigii* is abundant.

with the badly rusted plots, which raises the number to 136 and gives a ratio of 136 : 49 or 2·8 : 1.

A further examination of four of the plots containing both classes of individuals gave 149 rusty to 48 relatively rust-free or a ratio of 3·1 : 1, figures which again agree with one's expectation on the assumption that the liability is dominant over immunity.

Further experiments are now being carried out with a more immune wheat than Rivet, which I have only recently obtained.

Thick and Thin Glumes.

This particular pair of characters has not been specially investigated. I was struck by the fact, while rubbing out the ears of the F_2 generations of crosses with Rivet parentage, that many shed their grain readily whilst in others the grain was so tightly gripped in the florets by thick outer glumes that it was difficult to remove the grain on rubbing. Extreme cases were met with in which the spikelets remained altogether closed and on rubbing the rachis broke into fragments. An examination of the parents then showed that the Rivet wheat had thicker glumes than the other varieties, a fact which had escaped my notice earlier. These plants with closed spikelets and brittle axes had for the most part lax ears, but the corresponding compact forms were present. The one point of interest associated with them is that the closed spikelet and brittle rachis are the distinguishing characteristics of *T. spelta*. As a matter of fact the plants were so spelt-like that several people with a special knowledge of wheats have had no hesitation in referring them to this sub-species. Further, practically all of the commoner types of spelts were represented among the thirty individuals occurring in Red King × Rivet (F_2), and the smaller number in Rivet × White Monarch. There were beardless, bearded, grey, red, and white varieties (Plate I. fig. 6).

Six years ago this would have been a striking demonstration of "reversion" to a more primitive type. Now one has become somewhat suspicious of these reversions and one examines them more critically than hitherto. In the first case we have no evidence which conclusively shows that *T. spelta* is a primitive type. It has probably been considered as such, solely on account of this habit of breaking the rachis for "seed" dispersal, which is common in many of the wild grasses. Further than this I see no possibility of advancing in this direction.

One other possibility had to be considered. Red King and White Monarch are already complex varieties raised by the Gartons and it might have been that spelt wheats were used in building them up, which in some way or other had split off again. Mr John Garton has kindly given me their pedigree, which contains no spelt parentage[1].

Such considerations as these led me to take the view that these individuals were spelt-like but not true spelts, that they had originated simply as the result of a fresh combination of characters represented in the parents, the thickness of the glumes having been intensified just as the grey colouring has been shown to be. In support of this view it has to be mentioned that individuals occurred among the non-spelt-like forms which had thinner glumes than those of the thin-glumed parents, that is an intensification of the thin character. If the glumes increase in thickness then it becomes more difficult for the developing ovaries to push them open, and a point is reached at which the spikelets remain closed. Such intermediate stages do occur. The spelt-like appearance of the ear would thus be accounted for. The brittleness of the rachis is more difficult to explain, for it would seem that a fresh character, one not found in either parent, has appeared. Here again though difficulties arise, for one finds individuals in which the rachis is only slightly brittle, others in which it is more brittle, so that the new character has made its appearance in a series of steps, not outright. On the whole it seems to me most probable that brittleness is a character correlated with closed spikelets, as "seed" dispersal would be impossible without it. Since harvesting the F_2 generation in 1903 I have carefully compared these spelt-like ears with the corresponding varieties of *T. spelta*, and I have been still further struck by their similarity in general appearance. At the same time, whilst admitting that from a systematist's point of view they may be identical, they are not so to one who is accustomed to the more minute distinctions between varieties met with in agricultural practice. The two points of difference which appeal to me most are: (1) that the texture of the grain is that of our English varieties—it would not yield the fine pastry-flour so characteristic of spelts; and (2) the rachis of the true spelt is more brittle than that of the spelt-like ears among the Rivet crosses. The F_3 generation of these spelt-like wheats showed the same types of segregation as the other hybrid forms. The bearded, white individuals (*i.e.* recessive in

[1] It is perhaps worth pointing out here that in spite of the complexity of the parentage of these two varieties they are indistinguishable from pure varieties even on further crossing—a fact Mendel's work would lead one to expect.

both characters) bred true, the beardless either bred true or threw bearded and beardless individuals, the velvet-chaffed either bred true or threw velvet and glabrous, and so on, but the closed spikelets and brittle rachis were retained in each case.

General Conclusions.

Summing up the results obtained up to the present we find that for each pair of unit characters segregation occurs in such a way that the results obtained agree with those expected on the assumption that the gametes are pure with respect to the characters they carry. The characters either separate out in the F_2 generation (or in the case of certain seed characters in the F_3 generation) according to the usual ratio of $3D:1R$, when one of the pair is dominant and the other recessive, or when the dominance is imperfect as in the case of grey over white glumes, or in the ratio of two intermediates to one of each of the pair where neither character can be considered as dominant over the other.

These characters may be grouped as follows:

A. Those showing pure dominance and thus resembling those described in peas by Mendel:

Dominant	Recessive
Beardless ears.	Bearded ears.
Felted[1] glumes.	Smooth glumes.
Keeled glumes.	Round glumes.
Lax ears.	Compact ears.
Red chaff.	White chaff.
Red grain.	White grain.
Thick and hollow stem.	Thin and solid stem.
Rough leaf surface.	Smooth leaf surface.
Bristles on stem.	Smooth stem.
Large sclerenchyma girders associated with an angular stem outline.	Small sclerenchyma girders and an almost circular outline.
Hard, translucent endosperm.	Soft, opaque endosperm.
Susceptibility to the attacks of Yellow Rust.	Immunity to Yellow Rust.

Where investigated in detail the ratio of $3D:1R$ has been found in F_2 for these pairs of characters.

[1] Where Rough Chaff is the felted parent.

B. Those showing irregular dominance; in F_1 some individuals show one of the pair in almost full intensity, but in others it may be hardly visible:

Felted glumes[1].	Glabrous glumes.
Grey colour of the glumes.	Red or white glumes.

In the F_2 the segregation is normal as in the preceding group.

C. Those in which there is no dominance of either character and the F_1 is intermediate between the parents in respect to the following pairs:

Lax and dense ears.
Large glumes and small glumes.
Long grains and short grains.
Early and late habit of ripening.

On segregation two of the intermediates occur to each of the pure characters, a ratio corresponding to $D:2DR:R$.

Mendel's laws of inheritance apply to morphological, histological, and constitutional characters, and one can probably recognize as many pairs of characters as there are minute differences between the varieties experimented with. The various shades of red in the grain, the various degrees of laxness of the ears, etc., are each represented by character units.

No indisputable case of "reversion" has occurred. Where hybrid varieties of known parentage are crossed with other varieties no indications of the parentage of these hybrid varieties, excepting the characters they themselves show, have been met with.

Any desired combination of the characters represented in any two varieties can be obtained "fixed" in the first or at the most the second generation from the hybrids.

In addition to the characters described above a number of others dealing with fertility, hardiness, differences in the aleurone layer, etc. are being investigated.

I take this opportunity of acknowledging much kindly assistance given me whilst this work was in progress; in the first place by my wife, who carried out much of the preliminary work of hybridizing and aided me in sorting out each generation and recording the characters of the individual plants; and also to Mr A. E. Humphries, who besides

[1] Where Rivet wheat is the felted parent.

providing me with many varieties has given me much valuable advice whilst dealing with the endosperm characters and other more technical matters with which I am not particularly familiar.

EXPLANATION OF PLATE I.

Fig. 1. (*a*) Stand-up White, (*b*) Bearded White, (*c*) the hybrid (F_1) Stand-up White × Bearded White, showing that the beardless condition is dominant over the bearded.

Fig. 2. (*a*) Red King, (*b*) Standard Red, (*c*) Red King × Standard Red. The hybrid (F_1) is lax eared, and the internode length slightly exceeds that of the lax parent Red King.

Fig. 3. (*a*) Hedgehog, (*b*) Devon, (*c*) the hybrid Devon × Hedgehog, this is intermediate between the parents in respect to the laxness of the ear. Note the short awns at the apex of the spike. They occur, not infrequently, in Devon wheat.

Fig. 4. (*a*) Rivet, (*b*) Polish, (*c*) the hybrid Rivet × Polish. It is intermediate in laxness and glume length between its parents.

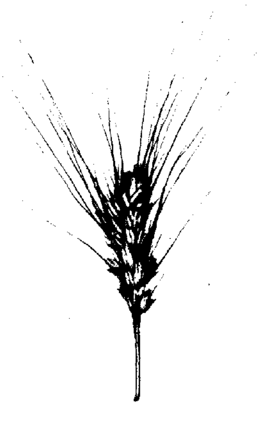
(a'), (a^2) dense and lax small glumed types of F_2,
(b'), (b^2) dense and lax large glumed types of F_2,
(c'), (c^2) dense and lax intermediate glumed types of F_2.
In (b') the awns have shed partially.

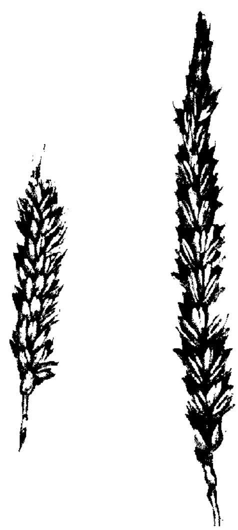
Fig. 5. Grains (*a*) of Rivet, (*b*) of Polish, (*c*) of the hybrid Polish × Rivet, F_1 plant generation.

Fig. 6. Beardless, spelt-like wheats showing the keeled glumes and closed spikelets. They are white, red or grey in colour.

Fig. 1.

Fig. 2.





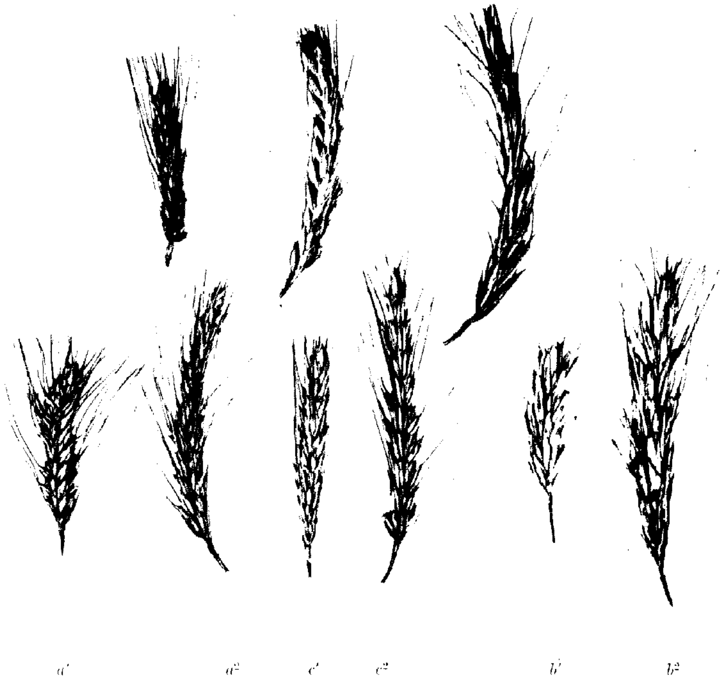
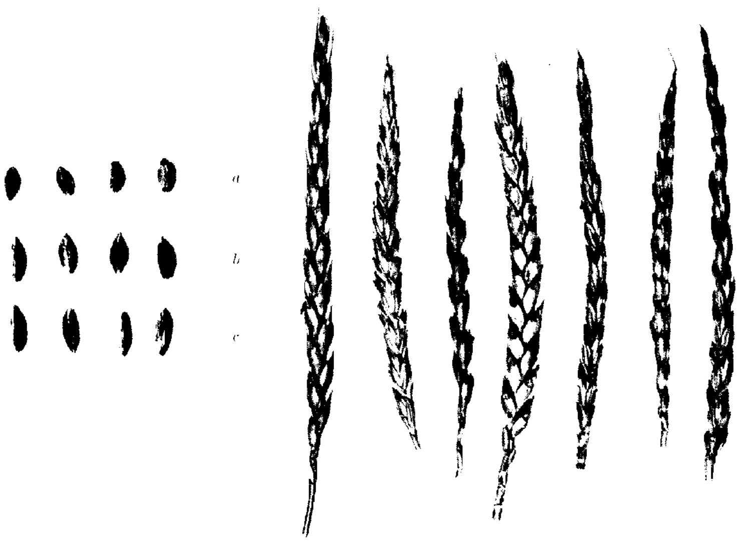


Fig. 4.



THE INFLUENCE OF POLLINATION ON THE DEVELOPMENT OF THE HOP.

By ALBERT HOWARD, M.A., F.L.S.,

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In general the hop is diœcious. Sometimes, however, in gardens of the Bramling variety, hills are met with from which bines arise bearing both male and female flowers. Such monœcious plants are rare.

The male flowers: The inflorescences bearing the male flowers are much-branched cymose panicles, arising either from the axils of the main stem or from the axils of the lateral shoots.

Each flower is about a quarter of an inch in diameter, and consists of a five-leaved sepaloid perianth, opposite which are five stamens with short filaments and long anthers, which liberate their pollen by longitudinal dehiscence (1, 2, 3, Fig. 1).

The female flowers: The female flowers occur in definite inflorescences (strobiloid spikes) which are borne on branches arising directly from the leaf axils of the main stem itself, or from the axils of the leaves upon lateral shoots produced by the main stem. These inflorescences give rise to the hops of commerce. Each female flower is very minute and consists of a cup-shaped perianth, partially surrounding the superior ovary, which contains a single ovule and which is surmounted by two long stigmas covered with elongated papillæ (4, 5, Fig. 1). At this stage (as a rule early in July) the hops are said to be "in burr." After the stigmas or "brush" of the young hops drop off there is a rapid growth of the bracts of the strobile, giving rise to the fir-cone shape of the mature inflorescence (7, Fig. 1). The bines are now said to be "in hop."

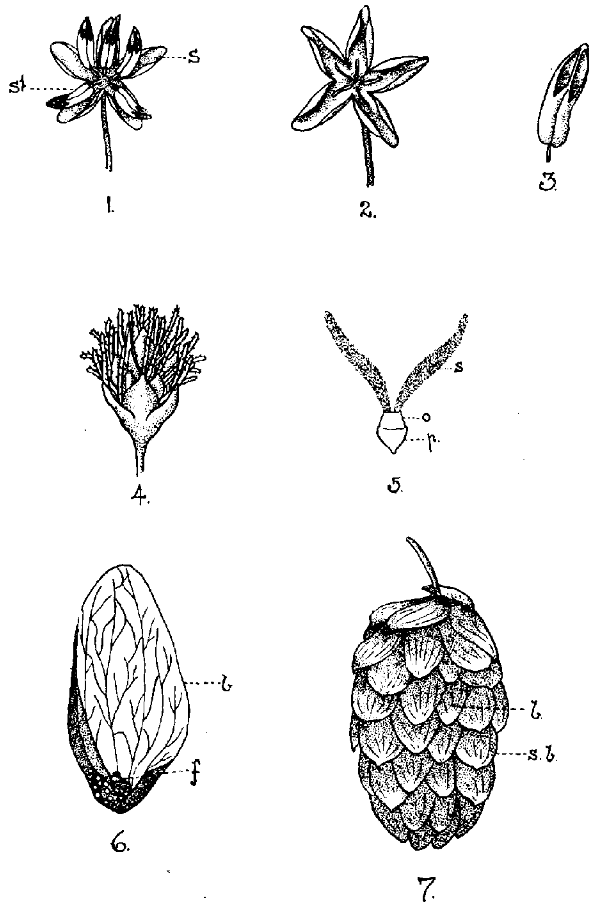

Fig. 1.

1.—A male hop flower. *s* perianth (sepal); *st* stamen.
2.—Perianth of male flower with anthers removed; the fine short filaments are visible.
3.—A stamen showing the dehiscence of the anther.
4.—A young female inflorescence (a hop "in burr") showing the stigmas ("brush").
5.—A complete female flower. *p* the cup-shaped perianth; *o* ovary; *s* stigma.
6.—A bracteole (*b*) surrounding the ripe fruit ("seed") *f*.
7.—A ripe hop showing the stipular bracts (*s b*) and bracteoles (*b*).

(1—6 × 3, 7 natural size.)

During the "growing out" period, which usually lasts about six weeks, it will be observed that there are two very distinct kinds of bracts in the strobile. At the four corners of the hop occur the seedless stipular bracts (7, Fig. 1), which are further distinguished by their greenish colour, the limited development of lupulin glands and their acuminate apex. On the flat sides, the rounded, bright yellow, seed-bearing bracteoles[1] (6, 7, Fig. 1) occur in pairs.

While carrying out various cross-fertilisation experiments during the past summer, it was noticed that the young hops which were not pollinated, and which served as check experiments or controls, always remained in burr for a much longer period (often more than a week) than those which were pollinated. On the other hand, it was found that when the young hops were artificially pollinated, the stigmas turned brown and withered in three or four days and then fell off. The dying away of the stigmas was at once followed by the growth in size of the young hops. In a word, the pollinated hops started to grow out at once, while those which had not received pollen did not develop immediately, but waited, as it were, for this process to take place. Thus as the pollinated hops began growth a week to ten days before the controls, it became a matter of great interest to follow the subsequent development of both.

It was found that the non-pollinated hops never recovered their lost ground. They turned out at picking time to be small, green and unripe, and compared very unfavourably with the well-grown, golden yellow and ripe pollinated hops. The difference between the two sets was so great in all respects that they would never have been taken for hops of one variety, much less for hops growing on the same bine and on opposite pairs of laterals. While the controls were very small and green, the pollinated hops only differed from the normal hops on the same bine in being rather more symmetrical and better developed specimens with the free ends well closed in.

The differences between the two sets of hops at picking time may be seen in Fig. 2, Plate II. The control hops are in the centre, the bunches on either side having been pollinated. Fig. 2 represents three bunches of Colegate's hops from the same bine, and developed from laterals of nearly equal strength. The control bunch in the centre is quite seedless, while the pollinated bunches on either side are well-seeded.

[1] The stipular bracts and bracteoles of the hop are spoken of as "petals" by the hop-growers.

A further point of some interest was noted when the experimental hops were picked. It was found that the controls, which in all cases turned out to be seedless, were attacked by mould (*Sphærotheca humuli*, [DC] Burr.) to a much greater extent than the seed-hops which had been pollinated. Indeed these latter were singularly free from this parasite. Fertilisation therefore seemed not only to stimulate the growth, to hasten ripening, and to improve the colour, but also to increase the mould-resisting power of the hop itself.

The behaviour of the experimental hops suggested the desirability of extended observations in hop gardens to determine, if possible, whether the above results, arrived at under somewhat artificial conditions, are borne out in actual practice.

In the first place, a very large number of nearly ripe hops were examined in order to determine to what extent seed-production takes place. *No well grown-out hops were seen without seeds.* Further, it was found possible to count the seeds in any hop by observing the size of the bracteoles. Where seeds have set, the bracteoles are much larger and brighter yellow than those which only bear rudimentary seeds. In Fig. 3, bracteoles with (A), and without (B) fully developed seeds are shown. In all cases those with mature seeds are larger than those with rudimentary seeds. The hops on the right and left (C) represent extremes of well grown-out seed hops. The two hops (E) are seedless hops from a control bunch, while (D) represents a hop from a pollinated bunch. The difference in size of the bracteoles with and without perfect seeds is well seen in the large hop on the left (C).

Since the stigmas at the stalk-end of the hop are ready for pollen first, after which those towards the free end become successively receptive, a considerable period elapses between the beginning and end of pollination in any particular hop. In view of the scarcity of males in many gardens at the present time it appeared probable therefore that hops would be found seedless at the base, fertile at the free end and *vice versâ*. A search showed that this was the case. In a garden which contained only three male hills in fourteen acres numerous hops were found seedless and small at the base, but fertile and enlarged at the free end. Others were found seedless and constricted in the centre only. Fig. 4 illustrates this point.

It was next noticed that fully developed seed hops and badly grown-out, unripe, seedless hops were often to be found on the same bine. In such cases, pollen was probably abundant when the earliest hops on

the bine were in burr, but was not available when the later hops were ready for pollination. Hence, in order to obtain all the hops on a bine in a well grown-out condition pollen must be available during the whole burr period.

Evidence on the subject of the special liability of seedless hops to mould attacks was now sought in the field. It will be remembered that in the cross-fertilisation experiments it was noticed that the seedless hops in the control bunches were attacked by mould to a much greater extent than the seed hops on the same bine. Accordingly, a large number of half seedless hops were examined to see whether the mould did more damage on the seedless part than on the seeded portion. This was found to be the case. The seedless portions were usually completely destroyed, while the fertile portions grew out almost normally (Fig. 5). Further, in hops which contained only one or two fertile bracteoles it was constantly seen that these structures were hardly affected, while the rest of the hop was destroyed (3–5, Fig. 5).

The above experiments and observations all point to the necessity of fertilisation in the production of well-grown hops of the desired colour. On the other hand, the absence of fertilisation leads to small, green, unripe hops, particularly liable to damage by mould. As is well known, it is during the burr stage that hops are liable to total destruction by mould. This seems, apart from climatic considerations, due to two main causes. In the first place, the feathery stigmas arrest the mould spores as they blow past, and also tend to keep the atmosphere around the spores moist and so assist in their germination. Secondly, unless pollination takes place as soon as the stigmas are receptive there seems to be a pause in development, during which the hop waits for the process to take place. It would appear, therefore, that any arrest of growth at this period is particularly dangerous, and everything should be done to carry the young hops rapidly through this critical phase.

It seems difficult, therefore, to escape the conclusion that, under the conditions obtaining in Kent, the growth of seed hops rather than seedless hops should be aimed at. Before, however, any special recommendations are made on such an important subject as this, it is proposed to carry out further investigations during the coming season on the lines indicated below. The present experiments are put forward merely as a contribution to the subject.

The advantages of growing seed hops seem to be the following:

1. Large, heavy, brightly coloured, and well grown-out specimens.
2. Early ripening.
3. Increased mould-resisting power.

The disadvantages, on the other hand, would appear to be:

1. The space taken up and the trouble involved in growing suitable males for the various gardens. It is obvious that unless the males shed their pollen when the hops are in burr they are useless as far as the particular garden in which they are growing is concerned. There seems to be quite as much variation in the time of ripening among male hops as there is among the females. Further, it appears that a good many of the males met with in hop gardens ripen too early and shed most of their pollen before the surrounding hops are in burr. Some trouble, therefore, would have to be taken to select and grow male hops which would correspond to the full burr period of the various varieties grown in the south-eastern districts of England. Probably suitable males could be raised from seeds.

2. The possible difference in brewing value between seed and seedless hops. The Germans say that 116 lbs. of seed hops are equal, in this respect, to 100 lbs. of seedless hops. Next season it is proposed to estimate the total resins present in equal weights of seedless and seed hops in several of the more important English varieties. With regard to this point, however, it might be mentioned that, in all the cases examined this year, it was found that the lupulin glands of the seedless hops were not so ripe at picking time as those in the seed hops on the same bine. This difference in ripeness therefore may lead to some difficulty in carrying out the proposed experiments.

3. The possibility of the more rapid exhaustion of the hills through the more frequent formation of perfect seeds. In order to throw light on this point an analysis of hop seeds (Early Bird Bramlings) has been made by Mr F. T. Holbrook. The results are given in the following table, together with the figures relating to the whole hop.

It will be seen that the seeds are richer in nitrogen and phosphoric acid. In view, however, of the liberal manner in which hops are manured, it is hardly likely that increased seed production will either exhaust the soil or weaken the plant.

The opinions of several leading Kentish hop-growers were now sought on this question of the value of male plants. The views ob-

Analyses showing the fertilising constituents contained in hops and seeds, stated in parts per 100 *of the materials as taken from the pocket.*

	Ash	Nitrogen	Potash (K_2O)	Phosphoric Acid (P_2O_5)	Lime (CaO)
Whole hops..............	6·33	3·22	2·45	1·18	1·06
Seeds......................	6·53	4·64	1·39	2·33	·46

tained differed widely. Many regard the males as useless and have them grubbed after picking time. Others, especially in East and Mid Kent, consider that a few males are useful and improve the general welfare of the gardens. Mr W. H. Hammond, of Canterbury, in a very interesting letter dated October 17th, 1904, sums up his experiences as follows:

"With regard to male hops in our gardens in East Kent, I have all my life understood from growers that they thought it an advantage to have a few male plants scattered about. My father, who was a large planter in the Petham Valley for sixty years or more, always grew a few males.

"The perfect seeds for one thing help to make weight, and our English brewers do not object to them, but apart from that many men seem, in the past, to have had an idea that it was better for the general welfare of the gardens if there were a few males present.

"I can recollect talking this matter over more than thirty years ago with the late Mr S. J. Sankey, of South Hill, Hastingleigh, when he instanced the case of a garden at Hastingleigh Court Lodge Farm, which had always been a good one and had always had a considerable number of male plants in it, but at one time a fresh tenant came who thought them useless, and destroyed them all; after that the garden moulded, went to the bad, and was soon grubbed.

"Personally, I have always thought it best to keep a few male plants in my own garden."

Mr H. O. Hubble, of Hunton, Maidstone, writes:

"I consider that the influence of the male hop in a hop plantation is decidedly a matter worthy of further experiments on your part, especially because the results you have already obtained seem conclusively to prove

what some growers in Mid Kent have for many years believed, as the result of observation only.

"I cannot pose as an 'experienced grower,' but I have often noticed that the female hops in close proximity to a 'seeder[1]' come into hop earlier, are larger and more mature, in fact are generally more 'complete,' if I may so put it, than those which are not so situated.

"The rule does not, of course, always hold good, but that, you have explained, is because the male hop has come to maturity either too early or too late for 'pollination' to take place.

"Your statement that a 'pollinated' hop is better able to resist mould is extremely interesting and valuable, and the fact that 'pollinated' hops always contain seeds is surely a weighty argument in favour of the preservation of the male plant.

"My uncle, a grower of long experience, has always insisted on the value of the male plants, and would always have some of them planted about each garden, and there are other large growers in this district who think and act in the same way."—(Letter, Nov. 4th, 1904.)

Turning now to the literature of the subject the greatest diversity of opinion is found. The German investigators seem to agree on this question, and regard male hops as useless or even harmful. It is even said that male plants are not allowed in Spält under a heavy penalty. The hops from this district, however, are not seedless, but contain seeds, so that the efforts made in striving after a seedless hop are not altogether successful.

The American growers, on the contrary, think that imperfect fertilisation is a frequent cause of light weight hops of inferior quality. A leading Oregon grower relates his experience as follows:

"This complaint of the Germans of seeds in American hops was first heard in 1882, when hops were so high, and caused some growers on this coast to grub out and destroy all their male vines. The result was that their hops did not mature well. They were large, green, light, feathery things, with neither colour nor strength, and dealers would not handle them. I have seen this experiment tried in Southern Oregon with the same result. I planted a yard myself once without being able to get male roots, and my hops were poor, lean things, until I obtained the male plants and got them to grow vigorously, when my hops became of good colour when ripe, with plenty of strength, and I heard no more complaints of poorly matured or lean hops. I am now fully

[1] In Kent, male hops are sometimes called "seeders."

convinced that hops, like many other plants, require fertilising from the bloom, and, as none but the male hop bears any pollen, it is necessary to have a sufficient number of these in a hop yard, so that the flowers of each vine may be fertilised. And brewers, if they expect a good, solid, bright-coloured, well-matured hop, well filled with lupulin, must expect also to see the hop well filled with good, large, purple seed. If they do not wish seed they cannot expect lupulin. Germany may produce good hops without seed, but it cannot be done here, at least such has been my observation and experience. Therefore my advice is to let the male hop alone, and if in a season of high prices a few brewers complain of extra weight in the seed, pay no attention, but go ahead[1]."

It must be remembered, however, that the conclusions of observers in Germany and the United States, although of great interest, are not necessarily applicable to the conditions which obtain in England. The varieties cultivated abroad are not the same as those grown in this country, the climatic conditions are widely different, and there does not seem to be the same danger from mould as in England.

The directions in which further work is desirable in this subject seem to be as follows:

1. The effect of pollination and its absence in gardens which are particularly liable to mould at the present time. It is well known that, other things being equal, mould is most prevalent where the air is still, and where the hops are "housed in." In such situations there is also the smallest chance of pollination, and it is possible that the lack of pollen may partly account for the damage done by mould.

2. The effect of pollination in gardens where the hops do not usually grow out well.

3. The influence of temperature and moisture on the liberation of pollen and the spread of mould. Generally speaking, damp, cold weather favours mould and also checks the liberation of pollen.

4. The possible relation between the percentage of seed and the total crop. Fertilisation seems to stimulate the growing out of the hop, and its absence has the reverse effect.

5. The comparison of the brewing value of seedless and seed hops. The determination of the total resins seems to be the best way of arriving at an opinion on this point.

6. Comparative infection experiments with mould on seed and seedless hops.

[1] *The Hop—its culture and cure*, H. Myrick.

7. The influence of pollen from different males on the development of particular varieties.

8. The effect of various washes on hops when in burr. Possibly fertilisation may be interfered with or even prevented when hops are sprayed at this stage.

9. The influence of seed formation on the "thickness" of the sample as taken from the pocket.

10. The effect of fertilisation on the compactness or "density" of the hop.

As far as possible these lines of enquiry will be followed up during the coming year.

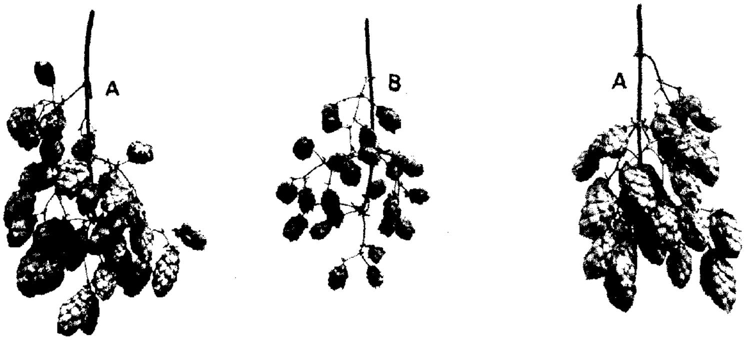

Fig. 2.—Seed and Seedless Colegate's Hops.

A.—Seed hops (pollinated). B.—Seedless hops (control—not pollinated).

Photographed 42 days after pollination.

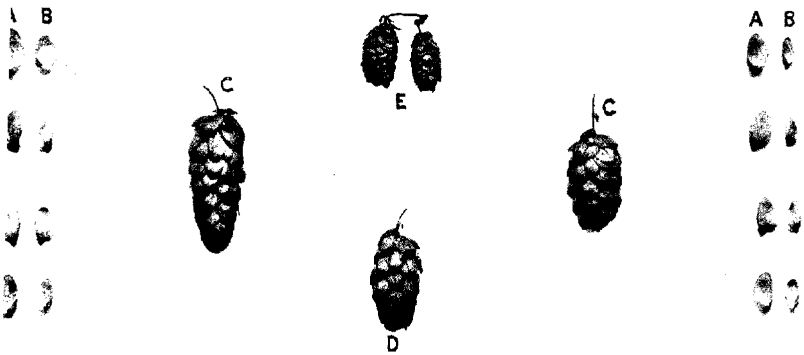

Fig. 3.—Seed and Seedless Hops and Bracteoles.

A.—Bracteoles with perfect seeds. C.—Seed hops (naturally pollinated).

B.—Bracteoles with rudimentary seeds. D.—Seed hops (artificially pollinated).

E.—Seedless hops (control—not pollinated).

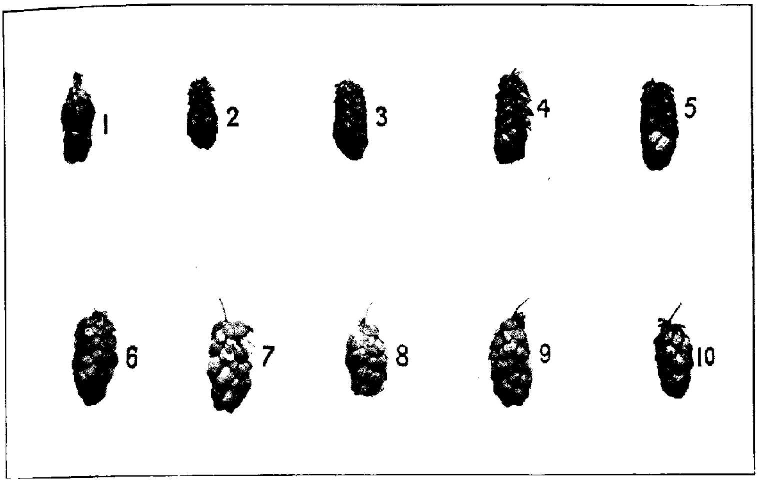

Fig. 4.—Partially Seedless and Seed Hops.

1.—Seedless in the middle only. 2 5.—Seedless at the stalk end only.

6-10.—Uniformly seeded and normally developed hops.

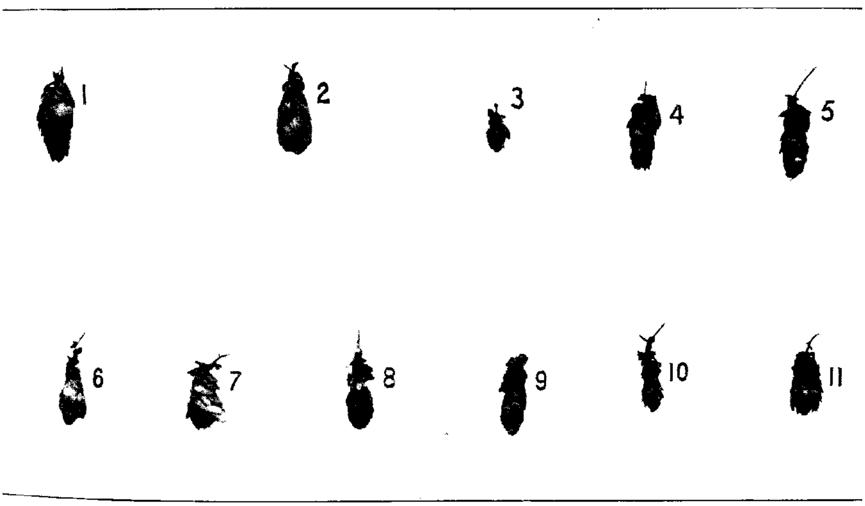

Fig. 5.—Hops attacked by Mould in the Seedless Portion.

1.—Attacked at the free end. 2.—Attacked at the stalk end.

3-5.—Fully developed fertile bracteoles in mouldy hops. 6-11.—Attacked in the seedless portion.

THE IMPORTANCE OF THE REMOVAL OF THE PRODUCTS OF GROWTH IN THE ASSIMILATION OF NITROGEN BY THE ORGANISMS OF THE ROOT NODULES OF LEGUMINOUS PLANTS.

A PRELIMINARY NOTE,

By JOHN GOLDING, F.I.C., F.C.S.,

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For nearly eighteen years the problem of the fixation of nitrogen by the root nodules of leguminous plants has been the subject of investigation by numbers of workers in many parts of the world, and steady progress has been made towards realising the conditions under which the organism works in the nodule. Artificial nutrient media have been prepared closely resembling the food supplied by the plant, and the organism itself has in recent years been induced to grow in artificial culture in the characteristic "bacteroid" forms approximating to those which are found in nature.

The actual process of fixation as it occurs in the nodule is, however, still wrapped in mystery, and experimenters have been well-nigh baffled in their attempts to produce it under artificial conditions; the results obtained being valuable mainly as affording proof that the plant itself is a leading factor in the process of assimilation, and plays a more important *rôle* than that of merely furnishing the organism with suitable food.

My own work on the subject, which has extended over some eight or nine years, has served to confirm the view that the plant was a more active agent than had previously been supposed, and that the solution of the difficulty lay in the direction of getting as closely as possible, not only to the natural conditions of food, but also to the natural conditions of the growth in the nodule.

With this idea I planned a series of new experiments, of which the main feature was the removal of the soluble products of growth

on lines similar to those which obtain in nature. This removal was effected by the use of a porous Chamberland filter-candle which was fixed in the culture vessel. Fairly aërobic conditions were also preserved by passing purified air through the cultures.

In the first experiments the parts of the plants taken were not subjected to any heat which might destroy the natural enzymes occurring in the nodules, though in later experiments assimilation was obtained in the sterilized extract from the parts of the plants, indicating that the plant enzymes did not play an important part in the assimilation obtained. In these first experiments in which the parts of the plants were simply cut up and well bruised in a mortar, the initial infection was provided by the organisms present in the crushed nodules. In later experiments with sterile liquids the cultures were inoculated from an agar slant of the pure organism from the nodules of the kind of plant under experiment, the organisms being scraped off with a sterile platinum needle and suspended in the liquid.

APPARATUS.

The apparatus used for these experiments consisted of three parts:—

(1) A porous filter-candle fixed in an inverted bell-jar and covered with another shorter bell-jar of the same diameter, in the neck of which was a rubber cork with three holes admitting two tubes bent at right angles, and a straight tube. This piece of apparatus could be sterilized by heat, and when removed from the steam sterilizer, the ground-glass rims of the bell-jars could be made quite air-tight by painting with sterile paraffin wax. All other openings were plugged with glass stoppers or cotton-wool.

(2) A filter-flask fitted with, (*a*) a long tube filled with cotton-wool, which tube was attached to the receiver of an air-pump; and (*b*) a rubber cork with one hole, through which passed a glass tube which was joined to the nozzle of the filter (1).

(3) An apparatus for purifying the air, consisting of two wash bottles and a long tube plugged with cotton-wool. The first of these wash bottles contained sulphuric acid and ferrous sulphate, the second wash bottle contained 50 c.c. of 10th normal sulphuric acid which was always found to require for neutralisation 50 c.c. 10th normal potash at the close of the experiment.

The apparatus (3) was joined to one of the bent tubes passing through the top of the bell-jar, the other bent tube being attached to an aspirator.

EXPERIMENT 1.

In the first experiment the material used consisted of, (*a*) the leaves and stem, (*b*) the roots and nodules of young bean plants, these parts were cut up fine, well bruised and sampled in a mortar.

The well-sampled materials were quickly weighed out, 500 grams of stems and leaves, and 20·02 grams of roots and nodules being taken for the experiment.

Portions were also weighed out into Kjeldahl flasks for duplicate determinations of the nitrogen in both parts.

Ammonia-free distilled water was then added to the crushed parts in the bell-jar (1). The air-pump and aspirator were set to work, and the apparatus left at the temperature of the room, which fell as low as 9° C.

On the third day an analysis of the air which had been aspirated through the crushed plants and water in the bell-jar, showed 8·6 per cent. carbon dioxide, and 8 per cent. oxygen. Oxygen gas was therefore substituted for air and passed through the apparatus for about an hour to encourage a more aërobic growth.

The receiver had to be changed from time to time as it filled. The filtrates were carefully measured and duplicate determinations of Nitrogen made in each lot by Kjeldahl's method, 100 c.c. being taken for each determination.

At the end of 15 days the solid residue was taken out, and when all the liquid had drained off, the wet residue and scrapings from the candle were well sampled, and the nitrogen determined in duplicate. No account was taken of the nitrogenous matter which might be left in and on the porous filter, it being thought that with so large a bulk of material this might be safely neglected if any considerable assimilation had taken place.

The results of this experiment are shown in the following table:—

	Nitrogen in grams.
500 grams of Stems and Leaves	2·865
20·2 grams of Roots and Nodules (quite fresh)	0·094
3000 c.c. Ammonia-free Distilled Water	0·000
Total Nitrogen to start with	2·959
2870 c.c. Filtrates and Drainings	0·731
566·2 grams of Wet Residue	2·570
Total Nitrogen after experiment	3·301
Total gain of Nitrogen during experiment	0·342

EXPERIMENT 2.

In this experiment the fresh unheated cold water extract from young pea plants was taken in a similar but smaller apparatus.

Five grams of pure dextrose were added in this case, but the solid matter of the plant was not used.

The results obtained were as follows:—

	Nitrogen in grams.
500 c.c. of Liquid Extract containing 5 grams of Dextrose	0·329
At the end of the experiment:	
400 c.c. of Filtrate contained	0·2632
72 c.c. of unfiltered Residue	0·0902
	0·3534
Total gain of Nitrogen during experiment	0·0244

EXPERIMENT 3. *Blank Experiment.*

In this experiment the apparatus was used as in Experiments 1 and 4. 1500 c.c. of nutrient medium as used in Experiment 4, was placed in the bell-jar containing the Pasteur filter, the nozzle of which was closed with a piece of rubber tubing plugged with a sterile glass rod.

The whole of this part of the apparatus was then sterilized in the steam sterilizer at 100° C., the rims of the bell-jars being sealed with paraffin wax while still hot. The other parts of the apparatus were now joined up and the filtration allowed to proceed slowly as in the case of the other experiments.

At the close of this blank experiment, the following result was obtained:

	Nitrogen in grams.
1500 c.c. Sterile Nutrient Medium to start with...	0·2422
Filtrate and Residue after experiment	0·2418
Loss of Nitrogen in blank experiment ...	0·0004

EXPERIMENT 4.

The object of this experiment was to find out if the assimilation of free nitrogen could be made to take place under the conditions of experiment when a *sterilized nutrient medium* and *a pure culture* were used.

The apparatus used was exactly the same as in Experiment 3, the medium to be used was well sterilized in the bell-jar.

A measured quantity of the suspended scrapings from a pure agar slant was added when the liquid had sufficiently cooled.

The nutrient medium was made up as follows:—

To 1 litre of sterile Pea extract was added, 3·3 grams of Dextrose; 6·67 grams of Cane Sugar; 1·0 gram of Dipotassium Phosphate; 0·5 gram of Magnesium Sulphate; 0·1 gram Succinic Acid; 0·03 gram Sodium Chloride; 0·03 gram Ferrous Sulphate; 0·03 gram Manganese Sulphate.

The experiment lasted 13 days. The results obtained were as follows:—

	Nitrogen in grams.
1500 c.c. Nutrient Medium contain	0·2422
50 c.c. pure Culture	0·0096
Nitrogen to start with	0·2518
800 c.c. of Filtrate contain	0·1434
730 c.c. „ „	0·1042
Insoluble matter washed from filter	0·0357
Nitrogen at the end of the experiment	0·2833
Total gain of Nitrogen	0·0315

EXPERIMENT 5.

This experiment was the same as Experiment 4, except that a much smaller apparatus was used and the experiment was continued for 22 days.

Result.

	Nitrogen in grams.
50 c.c. of pure Culture in water	0·0093
200 c.c. Nutrient Liquid	0·0924
Total Nitrogen to start with............	0·1017
On filter	0·0326
244 c.c. filtrate	0·0761
Nitrogen at end of experiment	0·1087
Total gain of Nitrogen	0·007

Attempts were made to grow the organisms on agar cultures spread on porous drying plates, which were floated on dishes containing dilute sugar solutions and covered with glass lids, purified air being passed over the surface.

Agar cultures were also made in sterile parchment dialysers floated on sugar solutions; and also in porous pots surrounded by sugar solutions. The results in all these cases were unsatisfactory.

Other experiments were tried in which the sterile liquids used above were placed in large flat-bottomed flasks arranged in series and inoculated with pure cultures. Purified air was passed over these cultures but in no case did any appreciable assimilation of nitrogen take place, the loss or gain of nitrogen did not exceed the limits of experimental error.

In some of these experiments large quantities of sugar solution were fed to the culture day by day, from sterile separating funnels; but though conditions obtaining in the plant were thus imitated in another respect, the results were not nearly so satisfactory as the cases in which the removal of soluble products was accomplished by means of porous filters.

Further experiments are now being conducted on the subject; a Novy's filtering apparatus being used instead of the apparatus (1), pressure is also being used instead of suction to make the liquid pass through the filter, thus getting nearer again to the natural conditions.

Conclusion.

The results of these experiments, in which larger amounts of nitrogen have been assimilated in artificial cultures than in any previous experiments, indicate that the conditions of growth obtaining in culture vessels fitted with a porous filter through which the soluble products of growth of the organism are being slowly removed, favour the assimilation of nitrogen.

It thus seems probable that one of the functions of the host plant is the removal of soluble products of growth, which when present in previous artificial cultures have prevented the assimilation of nitrogen.

THE ANALYSIS OF THE SOIL BY MEANS OF THE PLANT.

By A. D. HALL, M.A.,

Director of the Rothamsted Experimental Station (Lawes Agricultural Trust).

ONE of the main problems placed before the agricultural chemist is the estimation of the requirements of a given soil for specific manures, or the interpretation, by means of data obtained in the laboratory, of the behaviour of the soil towards these manures, as seen in properly arranged field experiments. For various reasons the obvious method of determining the proportions of Nitrogen, Phosphoric Acid, and Potash in the soil fails in many cases to give the required information; even the more modern methods of measuring only the quantities of these materials which are attacked by weak acid solvents, and in consequence regarded as available to the plant, by no means always accord with the results of experience. Hence from time to time attempts have been made to attack the problem from another side and to use the living plant as an analytical agent. The scheme is to take a particular plant grown upon the soil in question, and determine in its ash the proportions of constituents like phosphoric acid and potash. Any deviations from the normal in these proportions may then be taken as indicating deficiency or excess of the same constituent in the soil and therefore the need or otherwise of specific manuring in that direction. The theory rests on two assumptions, first that each plant has a typical ash composition, constant when the plant is grown under similar conditions; secondly that the variations in the proportion of such a constituent as phosphoric acid will reflect the amount of that plant food available in the soil, as measured by the response of the crop to phosphatic manuring. From this point of view a number of investigations have already been made: Hellriegel[1] discussed the relative

[1] *Landw. Vers. Stat.* II. 1869, p. 136.

variations of the proportion of potash in the ash of barley straw and of the soil in which it was grown; Heinrich[1] analysed the roots of oats and fixed certain minima, below which the need for specific manuring was indicated.

Atterberg[2] used the oat plant in his researches and established a series of minima for both the whole plant and the grain, from which the soil conditions could be deduced.

Godlewski[3] analysed the ash of crops of wheat, potatoes, and barley grown on experimental plots on a particular soil, so as to compare the variation in yield induced by specific manures with the variation in the composition of the ash.

The following experiments were undertaken with a view of testing the general applicability of the method and of measuring its agreement with the usual processes of soil analysis.

I. The Composition of the Ash of Oats grown in various Soils.

The first experiments were made with oats in pots in 1902. Six soils were selected representing widely varying types, of whose reaction to fertilisers in the field something was already known, and two glazed pots holding about 20 kilos. were filled with each soil. Black Tartarian oats were sown in all and finally reduced to 8 plants in each pot, these were harvested in July when the corn was partly formed but before it was ripe. The whole of the growth above-ground was cut away, dried, burnt, and the potash and phosphoric acid determined in the ash. Analyses were made of the soil used for each pot; "total" phosphoric acid and potash were determined in the solution obtained by digesting the soil with concentrated hydrochloric acid in a loosely stoppered flask on the water-bath for two days; the "available" constituents were estimated by Dyer's method of digesting with a one per cent. solution of citric acid[4].

The following tables show, I. The amount of dry matter and ash produced in each pot; II. The composition of the ash and of the soils as regards potash and phosphoric acid.

[1] *Grundlagen z. Beurtheilung der Ackerkrume*, 1882. [See also Dickow, *Jour. Landw.* XXXIX. 1891, p. 134, and Helmkampf, *ibid.* XL. 1892, p. 168.]

[2] *Landw. Jahr.* XV. 1886, p. 415; XVI. 1887, p. 757; *Jour. Landw.* XLIX. 1901, p. 97.

[3] *Zeitsch. Land. Vers. Wesen in Oesterreich*, IV. 1901, p. 479.

[4] *Trans. Chem. Soc.* 1894, p. 115.

TABLE I.

Dry Matter and Ash of Oats in Pots, 1902.

	Dry Matter grammes	Ash grammes	Ash °/o in Dry
Folkestone Sand ...A	19·1	2·5385	13·29
,, ,, ...B	19·0	2·1150	11·13
Chalk ....A	17·9	2·0212	11·29
,, ...B	15·2	1·5716	10·34
Brick Earth ....A	23·7	2·2544	9·51
,, ,, ...B	22·6	2·1350	9·45
Gault ....A	17·36	1·2851	7·40
,, ...B	17·55	1·0634	6·06
Weald Clay ....A	17·45	1·3648	7·82
,, ,, ...B	17·32	1·3538	7·82
Tunbridge Wells ...A	25·3	2·0551	8·12
,, ,, ...B	23·8	2·4762	10·40

TABLE II.

Oats grown in Pots.

Season, 1902.

	In Ash °/o			In Soil °/o	
	A	B	Mean of A & B	Total	Citric acid soluble
PHOSPHORIC ACID					
Folkestone Sand ...	9·15	12·63	10·89	0·351	0·142
Brick Earth	7·19	7·74	7·46	0·162	0·0401
Gault Clay	5·92	6·29	6·10	0·182	0·0144
Chalk	5·26	5·56	5·41	0·14	0·0115
T. Wells Sand	5·02	4·58	4·80	0·1117	0·021
Weald Clay............	3·51	4·31	3·91	0·063	0·0023
POTASH					
Weald Clay	33·4	32·0	32·7	0·528	0·024
Folkestone Sand ...	19·5	26·2	22·85	0·648	0·035
Brick Earth	20·01	20·1	20·05	0·468	0·016
Gault Clay	16·4	21·7	19·05	0·614	0·018
T. Wells Sand	16·5	19·6	18·05	0·144	0·028
Chalk	11·6	12·74	12·17	0·181	0·0125

Considering first the phosphoric acid results, it will be seen that the order in which they stand according to the proportion of phosphoric acid in the ash is substantially the same as the order indicated by the citric acid soluble phosphoric acid in the soil. The Folkestone Sand which stands at the top is clearly abnormal; the sample of soil was taken from a poor arable field on this notoriously poverty-stricken formation, much of which in the immediate neighbourhood consists of barren sandy heaths, but evidently it must have been drawn where a dung-heap had recently stood, or something equivalent had occurred, so high are the proportions of phosphoric acid and potash. The exceptional proportion of citric acid soluble phosphoric acid is reflected in the very high proportion of this constituent also present in the ash. At the other end of the scale stands the Weald Clay soil with the low proportion of 3·91 per cent. phosphoric acid in the ash, and with the exceptionally low figure of 0·0023 per cent. of citric acid soluble phosphoric acid in the soil. The other figures are intermediate; although the Tunbridge Wells Sand with one of the smallest proportions of phosphoric acid in the ash shows a fairly high proportion, 0·021 per cent., of citric acid soluble phosphoric acid in the soil.

The field experiments on the various soils (putting aside the Folkestone Sand) indicate that only the Weald Clay is in specific need of phosphatic manuring. The Tunbridge Wells Sand, on which the oats contained but little more phosphoric acid than did those grown on the Weald Clay, has repeatedly shown in field trials no response to phosphates, standing in every respect in the greatest possible contrast to the Weald Clay. Looking at the results as a whole the determinations of citric acid soluble phosphoric acid indicate the characteristics of each soil towards phosphatic manuring much better than do analyses of the ash, the casual variation between the phosphoric acid in the ash of the two pots *A* and *B* on the Weald Clay being actually greater than the mean difference between the Weald Clay which needs phosphatic manuring and the Tunbridge Wells Sand which does not. The potash results are even more inconclusive; the ash analysis brings the Weald Clay to the top, and certainly this soil can supply all crops amply with potash. The ash analysis also brings the Chalk to the bottom, which again agrees with the result of field trials. But the oats on the Tunbridge Wells Sand contain little below the average amount of potash, whereas field trials had shown that the field from which this sample was drawn responded to potash manuring in a quite exceptional manner, a result again which is not indicated by the amount of citric

acid soluble potash in the soil. In these results also the casual variations from pot to pot are often greater than those induced by differences of soil.

The experiments above described were begun by Mr Guy L. Pilgrim, B.Sc., now of the Geological Survey of India; he prepared the pots and grew the oats until they were well advanced, he also prepared the soil for analysis and made some determinations before his departure for India.

II. Composition of the Ash of Cereals grown at Rothamsted.

In view of the unsatisfactory results thus obtained, the numerous ash analyses of the Rothamsted experimental crops were consulted to ascertain if they threw any further light on the question.

The amount of variation due to season and individuality must be ascertained before we can fix a standard from which to measure the deviations on the part of material grown on an unknown soil. The following table (III.) shows a comparison of the composition of the ash of the wheat crop, grain and straw, grown on certain of the permanent wheat plots at Rothamsted in two sharply contrasting seasons, 1852 being cold and a year of low yields, whereas 1863 was perhaps the most favourable season on record for the growth of wheat. It should be noted that previous to 1852 the manuring had not been exactly repeated year by year for Plots 7 and 11, but by 1863 the manuring had been repeated at least twelve times on these as on the other plots, so that the growth had then thoroughly settled down to the influence of the particular manuring adopted.

A consideration of these figures will show that the composition of the grain is but little affected by the manuring, the extreme variations in 1863 being from 31·54 per cent. to 34·42 per cent. of potash, and from 46·02 per cent. to 52·04 per cent. of phosphoric acid, variations of about nine and thirteen per cent. of the respective amounts. The seasonal variations between 1852 and 1863 amount to 9 per cent. for the unmanured plot and nearly 16 per cent. for the dunged plot as regards potash, and to 5·1 per cent. for the dunged plot as regards phosphoric acid. In other words, the seasonal variations in the composition of the ash of the grain are of the same order of magnitude as the variations induced by manuring. With the straw the variations in composition of the ash are more marked, but here again the variations due to season are almost as pronounced as those caused by extreme differences of manuring.

TABLE III.

Composition of Wheat Grain and Straw as affected by manuring and season (1852 and 1863).

Broadbalk Field, Rothamsted.

Plot		2	3	7	10	11
Manuring*		Farm-yard Manure	Un-manured	N P_2O_5 K_2O	N only	N P_2O_5
Weight per bushel, lb.	1852	58·2	56·6	56·0	55·9	55·6
	1863	63·1	62·7	62·6	62·6	62·5
Weight of 100 grains, grms.	1852	3·46	2·88	3·08	3·26	2·94
	1863	5·35	5·02	4·79	4·51	4·76
Grain to 100 Straw	1852	49·6	53·9	41·9	47·3	47·8
	1863	67·5	70·4	59·4	74·3	70·4
GRAIN						
Ash in Dry Matter °/₀	1852	1·98	2·03	1·95	1·83	1·96
	1863	1·85	1·95	1·73	1·56	1·72
Nitrogen in Dry Matter °/₀	1852	2·02	2·08	2·29	2·48	1·95
	1863	1·52	1·65	1·53	1·70	1·79
Potash °/₀ in Ash	1852	27·22	29·66	28·64	28·10	27·19
	1863	31·54	32·32	33·64	34·42	32·58
Lime °/₀ in Ash	1852	2·79	2·87	3·04	3·51	3·80
	1863	2·34	2·66	2·73	3·85	3·89
Phosphoric acid °/₀ in Ash	1852	54·69	51·79	52·48	52·92	53·18
	1863	52·04	51·58	49·90	46·02	49·74
STRAW						
Ash in Dry Matter °/₀	1852	7·04	7·04	5·55	5·60	6·10
	1863	6·42	7·12	5·22	5·40	5·48
Nitrogen in Dry Matter °/₀	1852	0·46	0·57	0·87	0·89	0·46
	1863	0·25	0·33	0·36	0·35	0·44
Potash °/₀ in Ash	1852	12·86	10·54	15·12	10·53	5·12
	1863	17·97	13·02	24·96	14·25	9·31
Lime °/₀ in Ash	1852	3·87	2·52	5·26	5·60	5·78
	1863	3·78	4·39	5·55	6·92	7·39
Phosphoric acid °/₀ in Ash	1852	3·21	3·56	3·73	2·50	3·21
	1863	3·16	3·16	2·78	1·73	2·81

1852.—Winter favourable, Spring dry and cold, Summer rainy and cold. Crop generally below average.

1863.—Winter very open, Spring mild and open, May and June rainy, July and August moderate to high temperatures. One of the best wheat years on record both for quality and quantity.

* For details of the manuring see *Memoranda of the results of field experiments at Rothamsted.* Lawes Agricultural Trust, 1901.

TABLE IV.

BROADBALK WHEAT.

Percentage Composition of the Grain ash, and Straw ash.
Mixed Sample representing 10 years, 1882–91.

	Plot 2	Plot 3	Plot 5 *b*	Plot 7 *b*	Plot 10	Plot 11 *b*	Plot 12 *b*	Plot 13 *b*	Plot 14 *b*
GRAIN									
Ash (Crude) in Dry Matter °/o	1·96	1·94	1·99	1·91	1·67	1·86	1·83	1·87	1·86
Iron peroxide &c.	0·65	0·81	0·69	0·66	0·85	0·70	0·63	0·68	0·59
Lime	2·46	3·06	2·67	2·85	4·32	4·13	3·57	2·90	3·49
Magnesia	10·94	9·96	10·34	10·32	10·10	10·11	10·00	10·17	10·59
Potash	30·70	33·12	32·56	31·90	34·58	32·35	32·14	32·86	32·59
Soda	0·08	0·15	0·09	0·11	0·26	0·20	0·11	0·12	0·13
Phosphoric acid	51·57	48·23	49·91	50·09	44·32	49·28	49·19	49·86	49·33
Sulphuric acid	0·77	1·86	1·18	1·20	2·96	1·39	1·84	1·15	1·27
Chlorine	0·03	0·25	0·12	0·15	0·91	0·02	0·11	0·07	0·10
Silica	0·81	0·75	0·71	0·61	0·79	0·57	0·55	0·52	0·55
Sand	0·43	0·81	0·75	0·49	0·83	0·73	0·38	0·54	0·38
Charcoal	1·57	1·06	1·01	1·65	0·29	0·53	1·51	1·15	1·00
Total	100·01	100·06	100·03	100·03	100·21	100·01	100·03	100·02	100·02
Deduct O=Cl	0·01	0·06	0·03	0·03	0·21	0·01	0·03	0·02	0·02
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
STRAW									
Ash (Crude) in Dry Matter °/o	8·13	7·69	7·95	5·89	6·03	5·84	5·69	5·93	5·52
Iron peroxide &c.	0·31	0·94	0·60	0·50	0·59	0·43	0·33	0·34	0·41
Lime	3·66	4·37	3·50	5·69	8·21	9·14	7·73	5·39	7·70
Magnesia	1·52	1·51	1·41	1·76	2·24	2·25	1·92	1·53	2·46
Potash	18·49	13·50	16·34	25·89	13·56	9·91	14·68	23·28	14·87
Soda	0·09	0·10	0·09	0·21	0·40	0·58	0·57	0·03	0·33
Phosphoric acid	3·89	2·97	4·25	3·82	2·12	4·26	3·65	3·39	3·87
Sulphuric acid	3·45	3·80	4·77	5·41	6·78	5·44	5·33	5·07	5·31
Chlorine	2·93	1·81	1·90	6·60	2·58	1·66	2·89	5·61	2·81
Carbonic acid	—	—	—	—	1·19	Trace	None	None	Trace
Silica	64·91	67·63	65·29	49·68	60·73	65·19	61·93	54·26	61·06
Sand	1·13	3·26	2·21	1·32	1·78	1·46	1·43	1·76	1·39
Charcoal	0·28	0·52	0·07	0·61	0·40	0·06	0·19	0·60	0·42
Total	100·66	100·41	100·43	101·49	100·58	100·38	100·65	101·26	100·63
Deduct O=Cl	0·66	0·41	0·43	1·49	0·58	0·38	0·65	1·26	0·63
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

For an abbreviated description of the manures see Table V.

To ascertain more fully the effects of the manuring upon the ash composition and to compare it with the analysis of the soil it will be convenient to take a later series of analyses of the Rothamsted wheat set out in Table IV, which shows the composition of the ash both of grain and of straw of mixed samples representing the crops grown in the decade 1882–91, *i.e.* after the manurial treatment had been continued 30 to 40 years without change. In the first place it will be seen that the figures bear out the conclusion already stated that the ash of the grain varies very little in composition; the highest percentage of potash is 34·58 and the lowest 30·70, while the phosphoric acid varies between 44·32 and 51·57 per cent. of the ash. In the straw the variations are much greater, between 9·91 and 25·89 per cent. of potash, and between 2·12 and 4·26 per cent. of phosphoric acid.

In the following table (V.) the phosphoric acid and potash figures given above are recalculated for the ash of the whole plant and compared with the analyses of soil from the same plots in 1893, as made by Dr B. Dyer[1].

The phosphoric acid shows but small variations, the only sample noticeably low is that derived from Plot 10, where continuous cropping with ammonium salts and without any phosphoric acid has seriously depleted the soil of this latter constituent. The soil analyses show that the unmanured Plot 3 is equally short of phosphoric acid, but as in this case there is an equivalent starvation in nitrogen and potash, the effect produced is a reduction of yield unaccompanied by any special variation in composition.

Turning to the potash plots, it will be seen that the variations are rather greater and are in accord both with the known manurial treatment of the plots and with the determinations of citric acid soluble potash. The wheat from the four plots 7, 13, 2, and 5 which receive potash annually, gives ash containing on the average 23·13 per cent. of potash; from the other five plots receiving no potash the proportion is only 16·93 per cent. If however we were using the analyses to indicate the need or otherwise of the soil for potash manuring, while the ash analyses show only a drop from 23 per cent. on the potash manured plots to 17 per cent. on the non-potash manured plots, on the same plots the citric acid soluble potash in the soil changes from 0·0278 per cent. to 0·0033 per cent., a step much more in accord with the known history of the plots.

[1] *Phil. Trans.* Vol. 194, pp. 235—290.

TABLE V.

Broadbalk Wheat (1882–91).

Plot	Manuring*	In ash of whole plant %	In Soil (1893) % Total	In Soil (1893) % Citric acid soluble
	PHOSPHORIC ACID			
14	Nitrogen, Phosphoric acid	11·97	·204	·0442
5	Phosphoric acid, Potash	11·89	·219	·0642
11	Nitrogen, Phosphoric acid	11·82	·197	·0405
7	Nitrogen, Phosphoric acid, Potash	11·41	·195	·0547
12	Nitrogen, Phosphoric acid	11·40	·201	·0413
3	Unmanured	10·99	·114	·0078
13	Nitrogen, Phosphoric acid, Potash	10·93	·205	·0434
2	Farmyard Manure	10·23	·215	·0560
10	Nitrogen only	9·06	·1245	·0074
	POTASH†			
7	Nitrogen, Phosphoric acid, Potash	27·38	·262	·0232
13	Nitrogen, Phosphoric acid, Potash	25·36	·273	·0188
2	Farmyard Manure	20·38	·285	·0384
5	Phosphoric acid, Potash	19·39	·279	·0308
14	Nitrogen, Phosphoric acid	18·26	·240	·0024
12	Nitrogen, Phosphoric acid	17·88	·223	·0040
3	Unmanured	17·42	·220	·0032
10	Nitrogen only	17·27	·237	·0036
11	Nitrogen, Phosphoric acid	13·80	·197	·0032

* For a full description of the manurial treatment of each plot see *Memoranda, &c., loc. cit.*

† Dr Dyer's determinations of total Phosphoric Acid and Potash were made in a solution obtained by evaporating the soil to dryness with strong Hydrochloric Acid and digesting afresh for one hour with more acid; the 48 hours' digestion previously described extracts about twice as much Potash from the same soils.

Table VI shows analyses of mixed samples of the ash of barley grain and straw from four plots for the ten year period 1882–91. As with the wheat the fluctuations in composition are in the main confined to the straw, the grain being comparatively constant in composition whatever the manuring. Table VII gives a comparison of the phosphoric acid and potash recalculated for the ash of the whole plant with

TABLE VI.

Hoosfield Barley.

Percentage Composition of Ash of Grain and of Straw.

Mixed Sample representing 10 years, 1882–91.

	Plot 1 A	Plot 2 A	Plot 4 A	Plot 1 AA
GRAIN				
Ash (Crude) in Dry Matter °/o	2·10	2·34	2·44	2·15
Peroxide of Iron	0·95	0·70	0·88	0·83
Lime	4·00	3·71	3·02	3·38
Magnesia	8·19	8·01	8·32	8·34
Potash	27·20	24·99	28·25	26·95
Soda	2·70	2·90	0·44	3·26
Phosphoric acid	33·17	37·71	38·98	34·16
Sulphuric acid	3·03	2·13	2·00	2·97
Chlorine	1·98	0·43	0·21	1·31
Silica	17·65	18·10	16·49	17·87
Sand	1·17	0·89	0·79	0·87
Charcoal	0·41	0·53	0·67	0·35
Total	100·45	100·10	100·05	100·29
Deduct O = Cl	0·45	0·10	0·05	0·29
Total	100·00	100·00	100·00	100·00
STRAW				
Ash (Crude) in Dry Matter °/o	4·65	4·71	5·26	4·68
Peroxide of Iron	0·68	0·63	0·61	0·59
Lime	11·72	14·67	9·67	11·20
Magnesia	2·18	2·40	1·63	1·86
Potash	12·72	7·17	28·99	12·63
Soda	10·22	11·54	1·81	14·00
Phosphoric acid	2·37	3·66	3·22	2·23
Sulphuric acid	5·85	5·57	5·92	6·26
Chlorine	8·78	7·03	9·06	4·15
Carbonic acid	1·36	1·41	2·43	2·74
Silica	43·25	44·89	36·24	42·91
Sand	2·70	2·46	2·12	2·15
Charcoal	0·15	0·15	0·34	0·21
Total	101·98	101·58	102·04	100·93
Deduct O = Cl	1·98	1·58	2·04	0·93
Total	100·00	100·00	100·00	100·00

TABLE VII.

HOOSFIELD BARLEY (1882–91).

Plot		Phosphoric acid			Potash		
		In pure ash of whole plant °/o	In Soil (1889) °/o		In pure ash of whole plant °/o	In Soil (1889) °/o	
			Total	Citric acid soluble		Total	Citric acid soluble
1 A	Amm.-salts only	11·75	·097	·0060	17·43	·267	·0020
2 A	,, + Phosphate	14·84	·173	·0425	13·14	·248	·0023
4 A	,, + Phosphate and Potash	13·97	·182	·0500	29·41	·326	·0298
1 AA	Sodium Nitrate only	11·66	·104	·0067	17·11	·136	·0050

the total and citric acid soluble constituents in the soil. The soil analyses were made by Dr B. Dyer[1] on samples drawn in 1889.

Inspection of these results shows that the variations in the proportions of phosphoric acid in the ash are too small to be of value in interpreting the condition of the soil towards phosphoric acid manuring, the information afforded by the weak citric acid being far more decisive. As regards potash the variations are very strongly marked, the barley plant from the one plot which had received potash containing about twice as much potash in the ash as did the three other samples from plots unmanured with potash.

These results are fully confirmed by a later series of analyses of the ash of the grain and straw grown on four of the same barley plots in 1903; the figures for phosphoric acid and potash are given in Table VIII, compared as before with the soil analyses.

All the plots receive the same manuring with nitrate of soda, but only Plots 2 and 4 receive phosphoric acid, and only Plots 3 and 4 receive potash. With phosphoric acid in the manure there is about 42 per cent. of phosphoric acid in the grain ash and 4·1 per cent. in the straw ash, dropping to 35 and 2·3 per cent. respectively when there is no phosphoric acid in the manure. The variations in the potash in the grain ash are small and not entirely in accord with the manuring. The potash content of the straw ash, however, varies greatly and in a very significant fashion; it is below 10 per cent. for Plots 1 and 2, which

[1] *Trans. Chem. Soc.* 1894, p. 115.

TABLE VIII.

HOOSFIELD BARLEY, 1903.

Plot	Manuring	Ash (pure) in Dry Matter %		In pure Ash %		In Soil (1889) %	
		Grain	Straw	Grain	Straw	Total	Citric acid soluble
	PHOSPHORIC ACID						
1 AA	Nitrate only	1·74	3·66	35·80	2·338	0·104	0·0067
2 AA	Nitrate and Phosphate; no Potash	2·27	3·71	42·27	4·179	0·165	0·0350
3 AA	Nitrate and Potash; no Phosphate	1·78	4·25	35·54	2·319	0·104	0·0082
4 AA	Complete	2·36	3·97	41·83	4·020	0·179	0·0475
	POTASH						
1 AA	Nitrate only	1·74	3·66	27·02	9·85	0·136	0·0050
2 AA	Nitrate and Phosphate; no Potash	2·27	3·71	29·93	6·42	0·142	0·0038
3 AA	Nitrate and Potash; no Phosphate	1·78	4·25	31·62	25·35	0·239	0·0350
4 AA	Complete	2·36	3·97	26·35	23·10	0·210	0·0305

receive no potash, it is above 20 per cent. for Plots 3 and 4 which receive potash.

Reviewing these results with cereals there did not seem much hope that the analysis of their ash would serve as a good indicator of the capacity of a given soil to supply phosphoric acid and potash for the crops. The grain varies but little in composition, even under the extreme differences in the soil which have been established at Rothamsted by long-continued manuring in particular directions, and though the straw shows very considerable fluctuation in its potash content it is not always possible to interpret the results. Putting aside the wide seasonal variation, other factors come into play; for example an unmanured plot impoverished in all directions may yield produce with much the same ash composition as one that is rich by being equally well supplied in all directions. Again, the supplies of other bases, soda, magnesia, lime, may themselves shift the normal proportion of potash. There is nothing in the results in fact to lead one to prefer the analysis of the ash to the analysis of the soil by means of weak citric acid, except the ash of barley straw which merits further examination.

III. THE COMPOSITION OF THE ASH OF ROOT-CROPS.

From the foregoing results it is clear that one difficulty in the process comes from a lack of sensitiveness in the plant; the variations in composition of the grain of a cereal are very small, even the fluctuations in the straw, though larger, reflect but imperfectly the great differences which are known to exist between the soils.

There are however reasons which lead us to suppose that cereals would afford but imperfect test plants; no other class of plant is so well able to obtain its necessary mineral constituents from the soil provided it is supplied with nitrogen, nor does any other crop maintain its yield so well under impoverished conditions of soil. A good example is afforded by the crops grown on the Agdell field at Rothamsted; this is farmed under the ordinary four-course rotation of swede turnips, barley, clover or fallow, wheat, and is divided into three main plots, which are respectively wholly unmanured, manured with phosphoric acid and potash but without nitrogen, and completely manured, the manuring being applied to the root crop only in each rotation. The following table shows the average crop during the last three completed rotations, *i.e.* after the plots had been subjected to the same treatment for the 44 previous years, and when in consequence the total impoverishment of the unmanured plot and the lack of nitrogen on the "minerals only" plot had become extreme.

TABLE IX.

	Unmanured	Minerals only	Complete Manure
	cwt.	cwt.	cwt.
*Swedes	22·1	195·4	451·6
*Barley (Total Produce)	18·8	16·4	23·4
†Clover Hay	15·6	54·5	69·6
*Wheat (Total Produce)	32·9	41·8	44·5

* The Swedes, Barley, and Wheat returns are for plots on which Clover is not grown but a bare fallow is taken in the third year of the rotation.

† Clover Crop of 1894 only.

It will be seen from this table that wheat and barley have maintained their production on the unmanured land in a remarkable fashion, for despite the extreme exhaustion of the soil on this plot the cereal crops it carries are only about 25 per cent. below the crops on the plot manured during each rotation. Nor does the mineral manuring on the

middle plot make much difference to the production of wheat and barley; as on the permanent wheat and barley plots at Rothamsted, mineral manures in the absence of nitrogen are of very little service to cereals. The clover crop feels the effect of the changed soil conditions to a much greater extent; the unmanured plot is able to grow but a very small crop less than a quarter of that on the completely manured plot. As might be expected from the power clover possesses of fixing atmospheric nitrogen, the mineral manure is almost as effective as the complete manure. With the swede turnips however the contrast is greatest; without manure they can barely grow at all, the production being only one-twentieth of that on the completely manured plot; they are also much helped by the mineral manures even in the absence of nitrogen, the production being increased nine-fold thereby. Clearly then clover, and especially swedes, are much better indicators of soil conditions than either of the cereal crops, which seem well able to obtain nutriment from the reserves that remain even in thoroughly impoverished soil. With these facts in view it seemed probable that the composition of the ash of the root crops would reflect the state of the soil in a more adequate fashion, especially as it is also possible to find root crops responsive to particular manurial constituents, *e.g.* potatoes and mangels to potash, and swede turnips to phosphoric acid.

Table X shows the proportion of potash and phosphoric acid in the ash of potatoes grown on three of the Rothamsted plots which had been under similar treatment for 25 years, compared with the total and available potash and phosphoric acid in the soil of the same plots a year later.

These results show that the variation of the composition of the ash of potatoes is not great in comparison with the very wide differences which exist in the composition of the soil, nor does it in any way agree with what we should expect from the known differences in the manurial treatment the crops have received. Again, the analyses set out in Table XI, though they belong to an earlier period—the first three years of the experiment, show that the potato ash does not vary much in composition with the very different manurial treatment to which the various plots were subject. One consideration will serve to explain this comparative constancy of composition; the potato tuber does not draw its nutriment directly from the soil, it is a secondary product of the plant's growth, a storehouse of reserve material that has been previously elaborated by the assimilating portions of the plant which deal with the raw materials of nutrition. Just as with the grain of

TABLE X. HOOSFIELD POTATOES.

Plot	Manures	Ash (pure) in Dry Matter (1896) °/₀	In pure Ash of "Ware" Tubers (1896) °/₀	In Soil* (1903) °/₀	
				Total	Citric acid soluble
PHOSPHORIC ACID					
1	Unmanured	2·83	9·00	0·087	·0090
9	Superphosphate	3·29	11·46	0·167	·0569
10	Complete Minerals...	4·35	8·83	0·178	·0582
POTASH					
1	Unmanured	2·83	52·18	0·299	·0074
9	Superphosphate	3·29	55·12	0·454	·0132
10	Complete Minerals ...	4·35	55·86	0·458	·0443

* After growing one crop of Barley following the Potatoes.

TABLE XI. HOOSFIELD POTATOES.

Percentage Composition of the Ash of "Ware" Tubers.

Mixed Sample representing 3 years, 1876–78.

	Plot 1	Plot 3 †	Plot 9	Plot 10
Ash (Crude) in Dry Matter °/₀	3·30	4·30	4·61	4·65
Peroxide of Iron and Alumina ...	0·40	0·36	0·30	0·32
Lime	2·15	1·43	1·53	1·54
Magnesia	3·60	3·25	3·33	3·41
Potash	55·50	57·48	57·77	57·58
Soda	0·19	0·12	0·32	0·53
Phosphoric acid	14·72	11·93	12·83	12·72
Sulphuric acid	8·70	5·85	5·65	6·14
Chlorine..............................	5·32	7·90	4·70	4·74
Carbonic acid	9·18	11·11	12·87	12·44
Silica	0·67	0·59	0·49	0·56
Sand	0·54	0·44	0·29	0·40
Charcoal..............................	0·23	[illegible]·33	0·98	0·69
Total	101·20	101·79	101·06	101·07
Deduct O = Cl...	1·20	1·79	1·06	1·07
Total	100·00	100·00	100·00	100·00

† Plot 3. Farmyard Manure every year.

cereals the plant tends to manufacture a product of constant composition, retaining in its primary organs any excess of a particular constituent it may have received from the soil.

The potato then, notwithstanding the dependence of its growth upon the potash supply, is not likely to make a good "indicator" plant; the mangel should be better, as it does feed directly on the soil and is very dependent on an abundance of available potash.

Table XII gives the proportion of phosphoric acid and potash in ash of the mangels from four of the Rothamsted plots, all of which receive

TABLE XII.

BARNFIELD MANGELS.

Plot	Manuring	Ash (pure) in Dry Matter* %	In pure Ash of whole plant %	In Soil (1900) %	
				Total	Citric acid soluble
	PHOSPHORIC ACID				
5 N	Nit. Soda + Super.	8·38	8·06	0·185	0·0453
6 N	,, + Super. and Pot. ...	8·05	7·78	0·176	0·0429
5 A	Amm.-salts + Super.	7·70	8·48	0·180	0·0483
6 A	,, + Super. and Pot.	8·04	7·48	0·149	0·0480
	POTASH				
5 N	Nit. Soda + Super.	8·38	12·83	0·345	0·0078
6 N	,, + Super. and Pot. ...	8·05	29·09	0·493	0·0435
5 A	Amm.-salts + Super.	7·70	17·83	0·481	0·0116
6 A	,, + Super. and Pot.	8·04	40·55	0·629	0·0501

* From determinations made in Mixed year samples of "Roots" and of "Leaves," 6 years, 1878–83.

the same amount of phosphoric acid, but only two of which, 6 A and 6 N, receive any potash. The plots receive equal quantities of nitrogen, but on the A plots in the form of ammonium salts, on the N plots as nitrate of soda. The table also shows the total and citric acid soluble potash and phosphoric acid in the soil seventeen years later, but as the manurial treatment of these plots had been practically unchanged since 1861 the difference in period is of little moment.

The phosphoric acid results are such as might have been expected, the variation is small, in accord with the fact that all the plots are heavily manured with phosphoric acid. But the variations in the potash are large and significant, the proportion rises on the nitrate of soda plots from 12·83 per cent. to 29·09 per cent. when potash had been used in the manure, and from 17·83 per cent. to 40·55 per cent. on the corresponding plots receiving ammonium salts. The soil analyses are naturally in accord, the citric acid soluble potash rises from 0·0078 per cent. to 0·0435 per cent. and from 0·0116 per cent. to 0·0501 per cent. with the use of potash in the manure. It is interesting to note in connection with these soil analyses how the long-continued use of nitrate of soda has lowered the total potash present in the soil of Plot 5 N; on this plot nitrate of soda and superphosphate form practically a complete manure and yield almost as large a crop as is obtained on Plot 6 N, whereas in the absence of both potash, and the soda to liberate it from the soil, 5 A gives a very small yield compared with 6 A.

The action of the sodium base is visible in another fashion in the ash analyses; it will be noticed that the potash content of the mangels on Plots 5 and 6 N, where nitrate of soda is used as a source of nitrogen, is considerably less than on the corresponding Plots 5 and 6 A, where ammonium salts take the place of nitrate of soda. On the non-potash plots (5 N and 5 A), the proportion of potash in the ash is 12·83 per cent. with nitrate of soda, and 17·83 per cent. with ammonium salts; on the potash plots the proportion is 29·09 per cent. with nitrate of soda, and 40·55 per cent. with ammonium salts. These differences are correlated with the amount of soda in the ash, as may be seen from the detailed analyses set out in Table XIII.

On Plot 5 N, with a deficiency of potash but an abundance of soda, the potash is as low as 12·83 per cent., the soda being up to 37·01 per cent., while on the corresponding Plot 5 A, equally deficient in potash but short also of soda, the yield is deficient for want of potash, but the proportion of potash to soda is about equal.

With Plot 6 N, where there is an excess of both bases, the plant takes up rather more potash than soda, 29 per cent. against 23 per cent., while on Plot 6 A, with abundance of potash but no soda, the plant contains 40·55 per cent. of potash against 9·69 per cent. of soda.

It is significant that the sum of the alkalis is practically constant where either one or both are obtainable, as on Plots 5 N, 6 N, and 6 A, but falls in the case of 5 A, where neither alkali is present in the

manure, its place being taken by an increased amount of lime, of which a large excess is available on all plots.

TABLE XIII.

BARNFIELD MANGELS.

Percentage Composition of Pure Ash of Whole Plant.

	Mixtures 6 years, 1878–83			
	5 N	6 N	5 A	6 A
Ferric oxide	0·62	0·63	0·93	0·64
Lime	5·53	5·63	16·29	7·88
Magnesia	2·33	2·22	4·43	3·09
Potash	12·83	29·09	17·83	40·55
Soda	37·01	23·05	19·54	9·69
Phosphoric acid	8·06	7·78	8·48	7·48
Sulphuric acid	4·59	4·44	4·46	3·38
Chlorine	4·74	4·30	14·92	15·03
Carbonic acid	24·34	22·64	15·51	14·49
Silica	1·01	1·19	0·97	1·16
Total	101·06	100·97	103·36	103·39
Deduct O = Cl	1·06	0·97	3·36	3·39
Total	100·00	100·00	100·00	100·00

TABLE XIV.

Percentage of Alkalis in Ash of Mangel.

Plot	5 N	6 N	5 A	6 A
Manuring	Soda, no Potash	Soda and Potash	No Alkali salts	Potash, no Soda
Potash °/o	12·83	29·09	17·83	40·55
Soda °/o	37·01	23·05	19·54	9·69
Sum of Alkalis	49·84	52·14	37·37	50·24
Lime °/o	5·53	5·63	16·29	7·88

These figures have an important bearing upon the question under consideration ; there is a difference of more than 11 per cent. in the proportion of potash in the mangel ash in the two cases where the soil contains an excess of potash, and there is a similar difference of 5 per cent. in the two cases where potash is deficient in the soil, these differences being due to the amount of soda present. Any abundance of soda acts as a diluent and reduces the proportion of potash in the mangel ash, even though the plant may have an excess of potash available. In consequence the normal proportion of potash in the ash of the mangel will vary with factors other than the potash content of the soil, especially will the presence or absence of sodium salts in the manure have a marked effect. From this we may conclude that if an ash analysis is to be used to indicate the manurial requirements of the soil, it is necessary that the roots analysed shall have been grown on an unmanured piece of the land in question.

IV. The Composition of the Ash of Swedes and Mangels grown on various Soils.

In accordance with the conclusions thus derived an attempt was made in 1903 to procure swedes and mangels grown on unmanured plots from field trials in various parts of the country so as to obtain a comparison of the ash and soil analyses with the results of actual experiment with the fertilisers in question.

Unfortunately in 1903 very few extended field trials were going on which would provide the right kind of material; Professor J. Percival, of Reading, obtained for me a number of samples from plots under his control, all of which showed great response to phosphatic manures; and through the kindness of Professor D. A. Gilchrist and Mr C. Bryner Jones, of the Durham College of Science, I was also provided with roots from land at Cockle Park and at Hamsterley, whose response to phosphatic and potash manuring was well known.

Table XV shows the results obtained with nine samples of swedes, all drawn from unmanured plots, except the Bisley sample, which was taken from an ordinary farm crop on the Bagshot Sand formation, the field being in high condition and manured with dung.

Considering first the phosphoric acid results in the field experiments, soils 1 to 6 show a considerable response to phosphatic manuring, whereas soils 8 and 9 seem able to supply ordinary crops with this constituent, the Arborfield sample No. 7 being rather a doubtful case.

TABLE XV.

SWEDES, 1903.

	Ash (pure) in Dry Matter %	In pure Ash %	In Soil %			
			Total	Citric acid soluble		Calcium Carbonate
					Extra Citric acid used	
PHOSPHORIC ACID						
1. Kirtlington	4·39	8·96	0·256	0·0013	0·0199	9·5
2. Wallingford	3·87	9·10	0·175	0·0014	0·0129	6·73
3. Hamsterley (Brierly Hill)	4·03	10·56	0·176	0·0203	—	0·62
4. Chipping Norton	4·55	10·91	0·187	0·0052	0·0123	4·0
5. Shenington	5·00	11·18	0·840	0·0128	0·0135	0·31
6. Blandford	3·14	11·81	0·121	0·0088	0·0080	1·68
7. Arborfield	3·75	12·77	0·049	0·0073	—	
8. Bisley	4·60	15·01	0·061	0·023	—	
9. Cockle Park	3·25	15·85	0·144	0·0324	—	
POTASH						
6. Blandford	3·14	22·82	0·340	0·0060		
9. Cockle Park	3·25	32·00	0·144	0·0112		
2. Wallingford	3·87	38·86	0·104	0·0057		
3. Hamsterley (Brierly Hill)	4·03	40·37	0·248	0·0210		
7. Arborfield	3·75	40·66	0·237	0·0227		
8. Bisley	4·60	40·81	1·40	0·027		
5. Shenington	5·00	43·36	0·287	0·0155		
1. Kirtlington	4·39	43·62	0·621	0·0072		
4. Chipping Norton	4·55	44·49	0·377	0·0192		

Putting this aside it will seem that the proportions of phosphoric acid in the ash of Nos. 1 to 6, which respond to phosphatic manuring, lie between 8·96 per cent. and 11·81 per cent., whereas the two not requiring phosphatic manuring show over 15 per cent. of phosphoric acid in the ash of the swedes. The soil analysis agrees in the main; the citric acid soluble phosphoric acid is exceptionally low for Nos. 1 and 2, which give extremely low proportions of phosphoric acid in the ash; and none of the other soils (except No. 3 with 0·02 per cent. citric acid soluble phosphoric acid) would be taken as properly provided with available phosphoric acid for a root crop, until the soils 8 and 9, which

are rich in citric acid soluble phosphoric acid, are reached. As some of these soils contained much carbonate of lime, determinations of this constituent were made and extra citric acid to neutralise it was added before making up the solvent to the 1 per cent. strength[1]. The results thus obtained are set out alongside those obtained in the usual way; with the chalky soils the extra citric acid naturally results in the solution of a much greater quantity of phosphoric acid, but the figures yielded by the ordinary 1 per cent. solution of citric acid are far more in accordance with the field experiments. The Shenington soil, No. 5, is a case not often met with; it contains as much as 0·84 per cent. of phosphoric acid, of which 0·0128 per cent. is soluble in citric acid, the latter being a fair amount for an arable soil, although it bears a very low proportion to the total phosphoric acid present. The explanation is to be found in the fact that the soil is derived from the Marlstone (Lower Lias) and is largely made up of hydrated ferric oxide, containing as much as 28·16 per cent. F_2O_3 in the air-dried soil, whereas ordinary soils only yield 2—4 per cent. to hydrochloric acid. This tends to show that an excess of ferric oxide, like calcium carbonate, keeps the soil phosphoric acid in an undissolved state and the soil water low in phosphoric acid, so starving the crop as regards this particular constituent.

The results with potash are set out in Table XV; of these soils only Cockle Park and Blandford are reported as responsive to potash manuring, and these are the two in which the percentage of potash in the ash falls much below 40 per cent. In this respect the results obtained by analysing the ash are more in accord with the field experiments than those obtained by the analysis of the soil. The citric acid soluble potash of the first two soils in the table is certainly low, lower than would be considered desirable for root crops, but two of the other soils give still lower results, which are not reflected in either the field experiments or the analyses of the ash. One of the soils from Bisley gives a very exceptional amount of total potash, especially considering that it is a light sand; however, the subsoil yielded even a higher figure, due to a glauconitic layer in the sandstone from which the soil is derived at this spot. An additional analysis of swedes from a manured plot at Hamsterley gives a further illustration of the way a nitrate of soda manuring will depress the potash content of the roots.

Unfortunately I was not able to procure any series of mangels from soils of known character; a few cases, however, served to give some idea

[1] Cousins and Hammond, *Analyst*, 1903, p. 238.

TABLE XVI.

SWEDES FROM HAMSTERLEY.

	Phosphoric Acid % in Ash	Potash % in Ash
Plot 1. Unmanured	10·56	40·37
,, 6. Manured with Nitrate of Soda and Superphosphate	11·59	33·97

of the normal composition of the roots for comparison with the Cockle Park mangels, grown on soil known to be in need of potash manuring.

The Cockle Park results for the three kinds of roots examined, potatoes, mangels, and swedes, are set out in Table XVII; the first

TABLE XVII.

ROOTS FROM COCKLE PARK, 1903.

	Average of others	Cockle Park		
	In Ash %	In Ash %	In Soil	
			Total %	Citric acid soluble %
PHOSPHORIC ACID				
Potatoes	15·93	19·44	0·16	0·035
Mangels	8·25	11·27	0·21	0·048
Swedes	11·29	15·85	0·14	0·032
POTASH				
Potatoes	59·45	54·05	0·21	0·018
Mangels	44·77	35·14	0·33	0·017
Swedes	41·74	32·00	0·14	0·011

column shows the average proportion of the phosphoric acid and potash in whatever other samples were available for 1903, the next three columns show the proportions in the ash of the Cockle Park roots and in the soil in which they were respectively grown.

The various results are in very satisfactory accord. It is known that the soil shows no specific need for phosphatic manuring and the proportion of phosphoric acid in each of the three roots is well above the average; the citric acid soluble phosphoric acid in the soil averages 0·038 per cent., a high figure. The soil is also known to need potash manuring; this is well brought out in the ash analyses, the ash of the mangels in particular showing a very low proportion of potash. The citric acid soluble potash in the soil averages 0·015 per cent., a figure not much below the amount usually found in arable soils.

Looking at these results as a whole the analysis of the swede ash indicates the character of the soil no better than, if so well as, the amount of citric acid soluble phosphoric acid, but the state of the soil as regards potash is much more readily interpreted from the composition of the mangel ash than from the amount of potash dissolved by the weak solution of citric acid. The determinations would seem to show that by the analysis of the ash of swedes and mangels grown on a given soil the manurial requirements of that soil, especially as regards potash, could be very well determined. But before such a method can be recommended as displacing the ordinary methods of analysing the soil, other test plants must be found. Swedes and mangels only answer the required purpose if they have been grown on an unmanured plot of the land in question, since manuring, even with substances other than those under examination, may quite disturb the composition of the ash. But it would be impossible in practice to obtain samples of swedes or mangels grown without manure of some kind, nor is it feasible to wait until these crops could be grown on specially unmanured land. Hence if the method of analysis by the plant is to replace that of direct analysis of the soil, some test plant must be found which grows pretty universally on all soils, in fact some weed of arable land that would be always available. It must be a weed fairly sensitive to soil conditions, resembling the root crops rather than the cereals, and its normal composition must be established at a particular stage of growth. Then a large number of analyses will be wanted of this plant grown under various soil conditions, until the extent of the ordinary fluctuations in its ash composition has been determined, so as to afford a basis for the interpretation of future determinations made on the ash of the same weed gathered from the soil under examination. It is in the direction of finding such a test plant that I am now continuing the work. The ash of barley straw also merits a little further consideration as a test material.

GENERAL CONCLUSIONS.

1. The proportion of phosphoric acid and of potash in the ash of any given plant varies with the amount of these substances available in the soil, as measured by the response of the crops to phosphatic or potassic manures respectively.

2. The extent of the variation due to this cause is limited, and is often no greater than the variations due to season, or than the other variations induced by differences in the supply of non-essential ash constituents—soda, lime, etc.

3. The fluctuations in the composition of the ash are reduced to a minimum in the case of organs of plants, which, like the grain of cereals, or the tubers of potatoes, are manufactured by the plant from material previously assimilated.

4. The composition of the ash of the cereals is less affected by changes in the composition of the soil than is that of root crops like swedes and mangels.

5. The composition of the ash of mangels grown without manure on a particular soil gives a valuable indication of the requirements of the soil for potash manuring. Similarly the phosphoric acid requirements are well indicated by the composition of the ash of unmanured swedes, though in this case determination of the citric acid soluble phosphoric acid in the soil gives even more decisive information.

6. Pending the determination of phosphoric acid and potash "constants" for some test plant occurring naturally on unmanured land the interpretation of soil conditions from analyses of plant ashes is not a practicable method by which chemical analysis of the soil can be displaced.

VARIATION IN THE CHEMICAL COMPOSITION OF THE SWEDE.

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THAT swedes are better feeding materials under some conditions than under others is more or less generally recognised; the suggestion of controlling these conditions is perhaps not new, but little of practical importance has been achieved in this direction. About five years ago the subject was considered at the Durham College of Science (now Armstrong College), Newcastle-upon-Tyne, and experiments were started which have been repeated and added to every season. The object of these investigations was to form a list of the different varieties of swedes in order of merit. Incidentally other points of interest have arisen, and are dealt with in the following pages. The results of these experiments have been published each year in the Annual Report of the Agricultural Department of the College, but a review of the work done seems of sufficient general importance to prove interesting to a larger circle of readers.

FEEDING VALUE AND "DRY MATTER."

It would be quite impracticable to carry out feeding experiments of a sufficiently extended range, to show directly the relationship between the live-weight increase produced by consuming swedes grown under all the varying conditions which occur in actual farming practice. It is possible, however, to find a simple chemical test which can indicate, approximately, the feeding value.

In order to find such a test a feeding experiment was carried out at the Experimental Farm of the Northumberland County Council[1], in

[1] Annual Report, 1902, and Bulletin, 1904.

which sheep were fed on rations exactly alike, except that some sheep received one kind of swede and some another kind, the swedes as well as the other foods being subjected to chemical analysis. The results of this experiment show that there is a very direct relationship between the feeding value and the amount of total "dry matter" in the swedes. Other experiments with cattle have yielded similar results. It is difficult, however, to trace any relationship between the feeding value of the roots, as determined by direct feeding experiment, and the amount of any other constituents, except the total "dry matter" and the carbohydrates. Since the amount of the carbohydrates is merely a difference figure obtained from the dry matter by subtracting the other constituents really determined, it is probable that the chemical determination of the "dry matter" is the most satisfactory means of determining the relative feeding value of swedes.

Purely theoretical considerations lead to the same conclusion. The water in the swede can have no value in itself, and all the other constituents are so easily digestible that no great error would result if the dry matter were considered to be completely digested.

As regards the different constituents of the dry matter, the amount of the carbohydrates is so large in comparison with the nitrogenous substances, that the effect of differences in the amount of the latter would be obliterated, supposing that the other foods used with the swedes supplied enough nitrogenous substances for the needs of the animal. If it were possible to obtain swedes with a large proportion of albuminoids, or if it were possible to fatten stock with little albuminoids in the other foods used, then it is unlikely that the determination of the "dry matter" by itself would be a sufficient guide to the feeding value of the swedes.

A point which is not quite certain from theoretical grounds is the relative feeding value of the sugar, and the other constituents included under the term carbohydrates. The feeding trial referred to above shows that there is probably no great difference in feeding value between sugar and other carbohydrates.

It must be pointed out that the foregoing remarks as to relative feeding values apply only when swedes are compared with swedes.

METHODS OF ANALYSIS.

Before the above experiments had been carried out a good many trials had been made on different methods of sampling and analysis. As a general result of these experiments I came to the conclusion that the best way of sampling was to take a core through the swede with an auger. It is very necessary that the core should go as nearly through the centre as possible, but I could not find any great difference between cores taken in different directions. The diameter of the auger should be small in comparison with that of the root; otherwise too great a proportion of the centre of the root would be taken. I originally came to the conclusion that the smallest number of swedes which must be sampled in order to obtain results representing a whole crop was 25, but experience has shown that this number is too small, and that samples taken from less than 100 roots give untrustworthy results. Even with this larger number it is better to have the results of three or four analyses and to average them before coming to any definite conclusions. A study of the figures in the final table will bear this out.

It is necessary that the analysis should be started before the samples have had time to dry; and it is difficult to chop the cores up or do anything else to them except weigh them at once and dry them. For drying the cores it is necessary to employ low temperatures, partly because it is almost impossible to get concordant results at high temperatures, and partly because at high temperatures the sugar is altered and in part decomposed, thus rendering the dried portions of no use for subsequent analysis. The limits I have adopted are 50° to 60° C., averaging as near 55° as possible. For this purpose special ovens were built, a complete description of which has already been published[1].

It is important to remember this temperature when comparing these results with the investigations of other workers, who usually dry their substances in a steam or water oven, at from 85° to 98° C., a simple convention having no real meaning excepting general convenience.

METHODS OF ELIMINATING DISTURBING CAUSES.

For the purpose of placing the different varieties of swedes in order of merit as regards feeding value, it is necessary to eliminate the effects of other factors than variety. This has been done in part experimentally, by growing swedes under conditions such that the other

[1] *Journal of the Society of Chemical Industry*, 1902, p. 1514.

causes are inoperative, and in part, mathematically, by calculating the extent of the disturbance due to other conditions and making the necessary correction.

Causes of Variation in Composition.

Before we can eliminate the effect of factors other than "variety" we must ascertain to what other factors variation is due. For this purpose we may imagine the percentage of dry matter (A) found by analysis to be the sum of a number of terms a, b, c ..., and we get the expression $A = a + b + c$ ..., in which we require to evaluate the terms a, b, c ..., each depending on one factor of variation[1].

The general aim of the following enquiry is to separate the causes of the variation in the composition of swedes under the heads of individuality, size, manuring, variety, season, soil, district, etc.

It is necessary to reduce the work to some compact form, and the method of treatment used enables the work on varieties to be represented in a small table (see Table VIII).

In some cases it will be necessary to exercise caution in drawing conclusions from the earlier experiments, as the importance of having a large number of swedes to the sample was not at first fully recognised.

The individual root. Samples taken from roots grown under the same conditions show considerable difference in the amount of sugar and dry matter contained in them. This can only be due to individual idiosyncrasy. In the case of sugar I found a variation of over 4 per cent.; and in the case of "dry matter" Wood and Berry[2] found a variation of about 7 per cent. These variations are greater than those due to any other cause. Considering these very large variations it should be obvious that a large number of roots must be cored in order to obtain a representative sample.

Size. In 1899 Monarch swedes were grown at Cockle Park under different systems of manuring, and these were so sampled that 25 large roots and 25 small roots were selected from each plot (Table I). The large ones were about 5 to 6 pounds in weight and the small ones 2 to 3 pounds. The sampling was done by slicing, as at this date the advantage of the coring method of sampling had not been proved, and as explained above 25 roots were then thought sufficient to give a representative sample. The variations due to size ranged from 1·75 to

[1] "Variation" is used to express "variation (or difference) in the percentage of dry matter in swedes"; "variety" to express "the variety (or kind) of swede."

[2] *Cambridge Philosophical Society's Proceedings*, March, 1903.

TABLE I.

Composition of large and small Swedes. 1899.

Monarch Swedes.

	A F.Y. Manure		B Artificial Manure		C F.Y. Manure and Artificials		D F.Y. Manure and Artificials		Averages				Average	
	Small	Large	Small	Large	Small	Large	Small	Large	A	B	C	D	Small	Large
mat- r %	11·41	9·66	10·77	10·37	10·64	9·99	10·55	9·59	10·53	10·57	10·31	10·07	10·84	9·90

A, B, and C were grown on Cockle Park, Northumberland.
D, grown at Longniddry, East Lothian, with same manures as C.

0·40 per cent. dry matter, the small ones being richer, but as the number of roots taken was small, part of this difference might be due to errors of sampling. The average, however, representing 100 large roots and 100 small roots, may be trusted, and shows that the small roots contained 0·94 per cent. more "dry matter" than the large roots. This amount of variation is similar to that found by other investigators.

Variation due to size therefore, although of importance, is less than that due to other causes. It may be eliminated by taking samples of a middle size, leaving out the very small and very large roots, an operation which introduces the personal equation of the man who samples. In the investigations on the other causes of variation, the effect of size has been minimised in this way, and by averaging results, in different years, in different places, and from roots sampled by different persons, it should be eliminated.

Manures. Table I shows the effect of different manures as well as the effect of different sizes on the amount of "dry matter" in the swede. Columns A, B, and C under "Averages," in which are given the percentage of "dry matter" for average-sized swedes grown at the same place, Cockle Park, in the same year, 1899, of the same variety, Monarch, but with different manures, give information on this subject. The maximum effect, that is the difference between columns B and C, is 0·26 per cent.; a small variation compared with that due to other causes.

In Table II are collected the results of other analyses of swedes

grown at various places with various manures. These differences in manuring are extreme and would never occur in practice (many of the experimental plots gave very small yields), yet the average effect of even such extreme manuring is only a small one, viz. 0·60 per cent. between the roots grown respectively with no manure and with a complete artificial manure.

In comparing different varieties, I have always compared varieties grown side by side at the same place, so that the differences in composition due to variety cannot contain any error due to the effect of the manure. The manures used at Cockle Park are the standard dressings of the College of Science, and do not differ from year to year, hence the variations due to season contain no error due to different manures. In comparing the results obtained from swedes grown at different stations in the North of England, the error introduced from neglecting variation due to manures may be appreciable, but will be all included in the variation due to "soil and district," a figure to which I do not attach much importance.

TABLE II.

SWEDES.

Variation in Composition due to Manures at seven stations in the County of Durham.

Station	Dry Matter %				
	Manures				No Manure
	Complete Artificial	No Nitrogen	No Phosphates	No Potash	
Cleatlam	10·17	10·48	11·18	10·83	11·61
Neasham Grange...	9·95	10·85	10·55	10·48	10·93
Medomsley E.	12·04	12·60	12·36	12·35	12·60
,, W.	10·88	12·05	11·11	12·08	12·24
Newlands Haugh...	9·91	9·57	10·45	10·39	9·69
Sherburn	12·51	11·19	10·15	10·44	12·49
Birtley	11·34	11·44	11·63	11·29	11·51
Average	10·98	11·18	11·06	11·12	11·58

The variety. This cause of the variation in composition is an important one, not only on account of its magnitude, but also because

the variety he sows is under the complete control of the farmer. Yield per acre is a very important consideration in the choice of a variety; but it is quite a different issue from chemical composition and feeding value and must be experimented on separately. Judging from the figures obtained at Cockle Park and from those published by other investigators, it appears unlikely that the yield per acre of any variety will prove as uniform as the amount of dry matter. The results of the investigations on the variation in composition due to variety are so constant that it is possible to average them all wherever the experiments have been carried out. In Table III are given the results of seven varieties of swedes grown at Cockle Park. The last column in the table gives the excess or deficiency of each variety in dry matter as compared with the average—11·23 per cent. These figures in the last column I propose to call the variety factor (v).

TABLE III.

Percentage of Dry Matter in Swedes grown at Cockle Park, Northumberland.

	1900	1901	1902	Average of years	Equals 11·23
Sutton's Crimson King	11·48	10·47	11·57	11·17	−0·06
Dickson, Brown and Tait's Best of All	10·83	9·63	12·13	10·86	−0·37
Drummond's Stirling Castle	11·37	10·58	11·85	11·27	+0·04
Kent and Brydon's XL All	10·47	9·92	11·23	10·54	−0·69
Fell's Bronze Top	12·38	10·41	12·48	11·78	+0·53
Webb's Arctic	11·77	10·87	12·39	11·68	+0·45
Carter's Holborn Kangaroo	11·73	10·38	11·84	11·32	+0·09
*Average of varieties	11·43	10·32	11·93		
Average of seven varieties for three years				11·23	
Effect of season (+11·23 in each year)	+0·20	−0·91	+0·70		

Season. In the last line of Table III is given the variation of the average figure for each season from the general average of all seasons. This figure in the bottom line I propose to call the season factor (s).

* See Table X.

Verification of results. The above analytical treatment may be made synthetical. In the expression $A = k + v + s$, A, the percentage of dry matter, may be calculated by adding together the constant, k (11·23 for Cockle Park), the variety factor, v, and the season factor, s. As k, v, and s, are all average results, the percentage of dry matter by calculation could only agree with the percentage found by chemical analysis, if the values for k, v, and s, were practically constant.

From the data set out in Table III we are now in a position to calculate what the composition of any variety in any season at Cockle Park ought to be, and to compare the results so obtained with that found by direct chemical analysis. For example in Table IV, Crimson King, 1900, calculated percentage dry matter

$$= 11{\cdot}23 - {\cdot}06 + {\cdot}20 = 11{\cdot}37.$$

If the two sets of figures so obtained agree well with one another, then the method of calculation must be correct. But what is a good agreement? If the two sets of figures "calculated" and "found" agree with one another as well as the duplicates of actual analyses, then the agreement is certainly a good one. I find that the average difference between duplicates of the samples analysed in 1902 was 0·31, between duplicates of all the samples to date 0·38.

For the sake of round numbers we can take 0·30 as the limit of good agreement. Of the 24 samples of swedes grown at Cockle Park and analysed (see Table III), there were 5 samples in which the difference between the duplicates exceeded 0·30; on comparing the "calculated" and "found" amounts as given in Table IV, it will be seen that the "calculated" amounts differ from the "found" amounts by more than 0·30 on only 5 occasions out of the 24. The agreement between "calculated" and "found" amounts is, therefore, a very good one; the method of investigation is justified and the figures obtained are verified.

Soil and District. These experiments have also been carried out at other places in the North of England besides Cockle Park (see Table V). The average of several varieties grown at different places differs from the averages of the same varieties grown at Cockle Park. Owing to the fact that the seven standard varieties were not all grown at the other stations, the variation in composition due to soil and district could not be calculated in exactly the same way as the variety factors at Cockle Park (Table III). For example, the four varieties grown at Neasham Grange (Table V) average 11·84 per cent. dry matter,

TABLE IV.

Showing Agreement between the Calculated and Found Amounts of Dry Matter in Swedes grown at Cockle Park, Northumberland.

	1900		1901		1902		
	Calc.	Found	Calc.	Found	Calc.	Found	
	%	%	%	%	%	%	%
Crimson King	11·37	11·48	10·26	10·47	11·87	11·57	...
Best of All	11·06	10·83	9·95	9·63	11·56	12·13	11·55
Stirling Castle......	11·47	11·37	10·36	10·58	11·97	11·85	...
XL All	10·74	10·47	9·63	9·92	11·24	11·23	11·58
Fell's Bronze Top	11·96	12·38	10·85	10·41	12·46	12·48	...
Arctic	11·88	11·77	10·77	10·87	12·38	12·39	12·22
Kangaroo	11·52	11·73	10·41	10·38	12·02	11·84	...

TABLE V.

Percentage of Dry Matter in Swedes grown at various stations in the Counties of Northumberland and Durham in 1902.

	Portrack Grange, Stockton	Kelloe Hall, Coxhoe	Neasham Grange, Darlington	Sherburn Colliery	Grange Hill, Bishop Auckland	Riffington, Cornhill-on-Tweed	Red Barns, Bishop Auckland	Cleatlam, Staindrop	Raby, Staindrop	Eshott, Felton	Billingham, Stockton
rimson King	...	...	11·64	11·45	11·76	12·37	...	...	...	...	...
est of All	...	12·06	11·30	...	...	...	12·27	12·33	...	...	12·92
tirling Castle......	11·78	...	...	...	12·75	...	...	...	12·73	13·30	...
L All	...	...	11·77	12·18	...	12·04	...	11·90	12·36	...	...
ell's Bronze Top	12·03	...	...	...	13·19	...	...	...	...	14·09	...
rctic	...	12·62	...	...	12·02	...	12·79	...	...	...	13·62
angaroo	...	...	12·65	11·60	12·25	13·66	...	...	...	...	...
rize Winner	...	12·07	...	...	12·25	...	12·49	...	...	...	13·20
arlington	11·10	...	...	...	11·48	...	...	12·35	12·70	12·56	...

and the same four varieties grown at Cockle Park for three years average 10·97 per cent. dry matter (Table III), to which must be added the season factor $+0·70$[1], making 11·67 per cent. The excess of Neasham Grange over Cockle Park is $(11·84-11·67)=+0·17$. In this way Table VI has been constructed.

[1] A shorter calculation is $A=k+v+s=11·23+\frac{-·06-·37-·69+·09}{4}+·70=11·67$.

TABLE VI.

Variation in the Percentage of Dry Matter in Swedes due to the Farm on which they are grown.

Station	1902		1903	
	$11{\cdot}23+s+f$	f	$11{\cdot}23+s+f$	f
Cockle Park, Morpeth	11·93	standard	11·67	standard
Portrack Grange, Stockton	11·48	−0·45	11·08	−0·59
Kelloe Hall, Coxhoe	12·14	+0·21		
Neasham Grange, Darlington	12·10	+0·17		
Sherburn Colliery, Durham	11·99	+0·06	12·15	+0·48
Grange Hill, Bishop Auckland	12·07	+0·14		
Riffington, Cornhill-on-Tweed	12·91	+0·98		
Red Barns, Bishop Auckland	12·33	+0·40		
Cleatlam, Staindrop	12·58	+0·65		
Raby, Staindrop	12·85	+0·92	11·25	−0·42
Eshott, Felton	13·16	+1·23	12·12	+0·45
Billingham, Stockton	13·15	+1·22		
Denton Grange West, Heighington			13·03	+1·36

The variations in percentage of dry matter, due to the farm on which the swedes were grown, do not appear to be the same in different seasons. The extent of the variation is important, 1·68 per cent. in 1902 and 1·95 per cent. in 1903[1]. I do not, however, propose to discuss this cause of difference in composition at present. The figure obtained may be used for abbreviating calculations, but its precise meaning may be left over; for want of a better name I call it the farm factor (f).

To trace the variety factor in the different counties I have constructed Table VII. The data for calculating the figures in the columns for Northumberland and Durham are given in Table X; the variety factors for Norfolk are calculated from the results published by Wood and Berry[2]. In calculating the Norfolk results I first averaged the three farms and then subtracted from each average such a number (12·08), that the average variety factor of the six varieties tested is the same (−0·17) in Norfolk and in the North of England. In only one variety, Crimson King, do the variety factors in different counties differ by more than 0·30, yet the extreme difference due to variety is 1·85. The difference between Northumberland and Durham is very slight. The variety factors, therefore, may be applied over large areas.

[1] $+1{\cdot}23-(-0{\cdot}45)=1{\cdot}68$ and $+1{\cdot}36-(-0{\cdot}59)=1{\cdot}95$.

[2] *loc. cit.*

TABLE VII.

Showing that the relative merit of varieties of Swedes is fairly uniform over a large area.

Variety of Swede	Variety factors in the County of		
	Northumberland	Durham	Norfolk
Dickson, Brown and Tait's Best of All	−0·31	−0·23	−0·31
Fell's Bronze Top	+0·77	+0·70	+0·62
Kent and Brydon's XL All	−0·67	−0·55	−0·61
Webb's New Arctic	+0·15	+0·24	+0·39
Kent and Brydon's Darlington	−0·29	−0·29	
Sutton's Crimson King	−0·35		−0·01
Garton's Model	−0·78		−1·08

The Constant and the Factors.

On page 96 I gave the expression $A = k + v + s$, where A was the amount of dry matter in the swedes, k a constant, 11·23, and v and s the variety and season factors respectively. The constant k was determined from only three years' experiments, a quite insufficient amount. A recalculation of k will give

1900	11·43 °/₀	dry matter in average swede $(k+s)$ (Table III)
1901	10·32 „	„ „ „ „ „ „
1902	11·93 „	„ „ „ „ „ „
1903	11·67 „	„ „ „ „ (Table X)
1904	14·96 „	„ „ „ „ „ „
Mean	12·06 „	„ „ „ „ „ „

It is probable that the average will be higher than 11·23, but the last two years have been so abnormal that it is useless changing the figure 11·23 until further experiments have been carried out.

The factor v depends on the subtraction of $k+s$ from A. The figure A is a single analytical determination and is liable to error, the expression $k+s$ is an average of many results and is not likely to be far from the truth. An average of several determinations of v will give a reliable result.

The factor v is supposed to represent the variation from the general

average of a "variety," which can only be defined for the purpose of these investigations as dependent upon the label on the outside of the packet in which the seed was bought. From the practical point of view this unsatisfactory definition does not matter, since the farmer must buy his seed in the same way. The character of varieties is quite certain to change in process of time and therefore the average of the seven standard varieties must change.

The conditions under which the seed was grown will probably influence the amount of dry matter in the swede; a study of the results will show that these fluctuations are probably of a temporary nature since the averages of five or more determinations of the variety factor v seem fairly constant (Table X).

In the case of Drummond's Extra Improved Purple Top there is, however, some evidence of a progressive increase.

The factor s is the difference between k and $k+s$, both of which are averages of large numbers of experiments. The factor k, however, can only be correctly determined after at least ten years' experiments, so that the season factor cannot be determined exactly at present. The relative effect of season can, however, be shown by the season factor whether the fundamental constant k is correct or not. The extreme seasonal variation found up to the present time is 4·64 per cent.—14·96 in 1904 and 10·32 in 1901. Further experiments may show an even greater range; and it is probable that season will rank as next in importance to individuality as a cause of variation.

How much of this seasonal variation is really due to meteorological conditions is uncertain. The time of sowing may affect the results, but then the time of sowing is itself to some extent dependent on meteorological conditions.

Composition of the Average Swede.

In feeding experiments it has sometimes been customary to assume an average composition for swedes. The above figures show that the average swede at Cockle Park during the last five years has averaged 12·06 per cent. of dry matter, and from Table VI it can be seen that the average farm in the North of England grows swedes rather richer than Cockle Park does. The average of all the farms tested is 0·46 more than Cockle Park in 1902, and 0·21 more than Cockle Park in 1903. Taking the mean (0·33), we find[1] 12·39 per cent. dry matter as the

[1] $12{\cdot}06+0{\cdot}33=12{\cdot}39$.

average for the North of England. Whether further experiments will increase or decrease this figure cannot be foretold, but it is certain that the figures commonly given in the text-books are too low.

CONCLUSION.

The results of all my experiments up to date are included in Table X, which contains all analyses except those of varieties which have been tested less than three times, and those individual analyses in which the duplicates differ by more than 1 per cent. There have been only three cases of such a large error, a small proportion of accidents which it is quite legitimate to ignore.

These analyses and calculations now enable us to draw up a list of varieties in order of merit (see Table VIII). This list, like a list already published[1], gives an order of merit solely depending upon the percentage of dry matter; the new list is, however, deduced from a much larger number of analyses of swedes grown at many different places and over a greater range of years.

For the sake of comparison I append the list first published (Table IX).

It only remains for me to thank members of the Durham College of Science, especially the past and present members of the agricultural staff, and the proprietors and managers of the farms named, for the facilities and kind assistance which they have at all times given me.

[1] Report of the Agricultural Department of the Durham College of Science, Newcastle-upon-Tyne, for 1901, p. 97.

TABLE VIII.

Order of Merit of Varieties of Swedes according to the percentage of total Dry Matter.

AVERAGE OF ALL RESULTS TO END OF 1904.

+0·7	Fell's Bronze Top
+0·3	Webb's Imperial
+0·2	Carter's Prize Winner, Carter's Holborn Elephant, Carter's Holborn Kangaroo, Drummond's Stirling Castle, Webb's New Arctic
+0·1	Drummond's Extra Improved Purple Top
0·0	Fell's Halewood Bronze Top
−0·3	Dickson, Brown and Tait's Best of All, Kent and Brydon's Darlington Bronze Top, Sutton's Crimson King
−0·6	Kent and Brydon's XL All
−0·8	Garton's Model Bronze Top.

TABLE IX.

Order of Merit of Varieties of Swedes according to the percentage of total Dry Matter.

	1900	1901
Best......	Fell's Bronze Top (12·38)	Webb's New Arctic (10·87)
	Carter's Elephant	Carter's Elephant
	Webb's New Arctic	Stirling Castle
	Carter's Kangaroo	Crimson King
	Crimson King	Fell's Bronze Top
	Stirling Castle	Carter's Kangaroo
	Extra Improved	Monarch
	Monarch	Extra Improved
	Best of All	XL All
	Model	Best of All
Worst ...	XL All (10·47)	Model (9·46)

TABLE X.

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 +s +f	Variety factor
Carter's Holborn Elephant.				*A*	*	*v*
Cockle Park 1900	11·83	12·13	0·30	11·98	11·43	+0·55
Cockle Park 1901	10·23	11·10	0·87	10·66	10·32	+0·34
Cockle Park 1904	14·78	14·50	0·28	14·64	14·96	−0·32
Eshott 1903	11·88	12·58	0·60	12·23	12·12	+0·11
Sherburn Colliery ... 1903	11·98	11·83	0·15	11·90	12·15	−0·25
Eshott 1903	12·67	12·66	0·01	12·66	12·12	+0·54
Average for North of England, all results						+0·16
,, ,, ,, ,, less highest						+0·08
,, ,, ,, ,, ,, lowest						+0·26
Carter's Holborn Kangaroo.						
Cockle Park 1900	11·57	11·89	0·32	11·73	11·43	+0·30
Cockle Park 1901	10·33	10·44	0·11	10·38	10·32	+0·06
Riffington 1902	13·78	13·54	0·24	13·66	12·91	+0·75
Cockle Park 1902	11·80	11·88	0·08	11·84	11·93	−0·09
Neasham Grange ... 1902	12·61	12·68	0·07	12·65	12·10	+0·55
Sherburn Colliery ... 1902	11·89	11·31	0·58	11·60	11·99	−0·39
Average for North of England, all results						+0·20
,, ,, ,, ,, less highest						+0·09
,, ,, ,, ,, ,, lowest						+0·31
Carter's Prize Winner.						
Cockle Park 1901	10·90	11·16	0·26	11·03	10·32	+0·71
Cockle Park 1902	11·61	11·84	0·23	11·72	11·93	−0·21
Cockle Park 1903	12·45	12·10	0·35	12·28	11·67	+0·61
Kelloe Hall 1902	11·87	12·27	0·40	12·07	12·14	−0·07
Grange Hill 1902	11·98	12·51	0·53	12·25	12·07	+0·18
Red Barns 1902	12·22	12·76	0·54	12·49	12·33	+0·16
Billingham 1902	13·00	13·40	0·40	13·20	13·15	+0·05
Average for North of England, all results						+0·20
,, ,, ,, ,, less highest						+0·12
,, ,, ,, ,, ,, lowest						+0·27
Dickson, Brown and Tait's Best of All.						
Cockle Park 1900	10·73	10·93	0·20	10·83	11·43	−0·60
Cockle Park 1901	9·28	9·99	0·71	9·63	10·32	−0·69
Cockle Park 1902	12·11	12·16	0·05	12·13	11·93	+0·20
Cockle Park 1902	11·59	11·51	0·08	11·55	11·93	−0·38
Cockle Park 1903	11·80	11·96	0·16	11·88	11·67	+0·21
Eshott 1903	11·64	11·81	0·17	11·72	12·12	−0·50
Eshott 1903	12·06	11·32	0·74	11·69	12·12	−0·43
Average for Northumberland						−0·31

* See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 $+s$ $+f$	Variety factor
Dickson, Brown and Tait's Best of All.				*A*	*	*v*
New Raby 1901	11·49	10·95	0·54	11·22	11·10	+0·12
Kelloe Hall 1902	12·12	12·00	0·12	12·06	12·14	−0·08
Neasham Grange ... 1902	11·60	11·00	0·60	11·30	12·10	−0·80
Red Barns 1902	12·10	12·44	0·34	12·27	12·33	−0·06
Cleatlam 1902	12·40	12·26	0·14	12·33	12·58	−0·25
Billingham 1902	13·23	12·62	0·61	12·92	13·15	−0·23
Denton Grange 1903	12·91	13·13	0·22	13·01	13·03	−0·02
Portrack Grange...... 1903	10·63	10·42	0·21	10·53	11·08	−0·55
New Raby............... 1903	10·70	11·60	0·90	11·15	11·25	−0·10
Sherburn Colliery ... 1903	11·80	11·87	0·07	11·84	12·15	−0·31
Average for Durham						−0·23
" North of England, all results						−0·26
" " " " less highest						−0·28
" " " " " lowest						−0·22
Drummond's Extra Improved.						
Cockle Park 1900	11·67	11·01	0·66	11·34	11·43	−0·09
New Raby............... 1901	10·41	10·91	0·50	10·66	11·10	−0·44
Cockle Park............ 1901	9·67	10·59	0·92	10·13	10·32	−0·19
New Raby.. 1902	12·82	12·36	0·46	12·59	12·85	−0·26
Eshott 1902	13·14	13·54	0·40	13·34	13·16	+0·18
Cockle Park............ 1903	12·40	12·50	0·10	12·45	11·67	+0·78
Cockle Park........... 1904	15·62	15·98	0·36	15·80	14·96	+0·84
Average for North of England, all results						+0·12
" " " " less highest						−0·00
" " " " " lowest						+0·21
Drummond's Stirling Castle.						
Cockle Park............ 1900	11·31	11·42	0·09	11·37	11·43	−0·06
Cockle Park............ 1901	10·53	10·63	0·10	10·58	10·32	+0·26
Eshott 1902	13·03	13·57	0·54	13·30	13·16	+0·14
Cockle Park............ 1902	11·78	11·93	0·15	11·85	11·93	−0·08
Cockle Park............ 1903	11·75	11·97	0·22	11·86	11·67	+0·19
Portrack Grange...... 1902	11·68	11·88	0·20	11·78	11·48	+0·30
Grange Hill 1902	12·58	12·92	0·34	12·75	12·07	+0·68
New Raby............... 1902	12·90	12·57	0·33	12·73	12·85	−0·12
Average for North of England, all results						+0·16
" " " " less highest						+0·09
" " " " " lowest						+0·20
Fell's Bronze Top.						
Cockle Park............ 1900	12·57	12·19	0·38	12·38	11·43	+0·95
Cockle Park............ 1901	10·05	10·76	0·71	10·41	10·32	+0·09
Eshott 1902	13·87	14·31	0·44	14·09	13·16	+0·93
Cockle Park............ 1902	12·52	12·44	0·08	12·48	11·93	+0·55
Cockle Park............ 1903	12·96	13·03	0·07	13·00	11·67	+1·33
Eshott 1903	12·63	12·70	0·07	12·66	12·12	+0·54
Eshott 1903	12·51	12·81	0·30	12·66	12·12	+0·54
Cockle Park............ 1904	15·85	16·49	0·64	16·17	14·96	+1·21
Average for Northumberland						+0·77

* See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/₀ Duplicates		Difference between duplicates	Average	11·23 $+s$ $+f$	Variety factor
				A	*	v
Fell's Bronze Top.						
Portrack Grange...... 1902	12·03	12·03	0·00	12·03	11·48	+0·55
Grange Hill 1902	12·83	13·55	0·72	13·19	12·07	+1·12
Denton Grange 1903	13·71	14·03	0·32	13·87	13·03	+0·84
Portrack Grange...... 1903	10·90	11·66	0·76	11·28	11·08	+0·20
Sherburn Colliery ... 1903	12·63	13·25	0·62	12·94	12·15	+0·79
Average for Durham						+0·70
,, North of England, all results						+0·74
,, ,, ,, ,, less highest						+0·71
,, ,, ,, ,, ,, lowest						+0·80
Fell's Halewood Bronze Top.						
Cockle Park 1900	12·08	11·56	0·52	11·83	11·43	+0·40
Cockle Park 1903	11·02	10·98	0·04	11·00	11·67	−0·67
Eshott 1903	12·03	12·03	0·00	12·03	12·12	−0·09
Sherburn Colliery ... 1903	12·09	12·13	0·04	12·11	12·15	−0·04
Eshott 1903	12·67	12·49	0·18	12·58	12·12	+0·46
Cockle Park 1904	14·45	15·35	0·90	14·90	14·96	−0·06
Average for North of England, all results						0·00
,, ,, ,, ,, less highest						−0·09
,, ,, ,, ,, ,, lowest						+0·13
Garton's Model Bronze Top.						
Cockle Park 1900	10·70	10·57	0·13	10·64	11·43	−0·79
Cockle Park 1901	9·16	9·76	0·60	9·46	10·32	−0·86
Cockle Park 1903	10·93	11·02	0·09	10·97	11·67	−0·70
Average for North of England						−0·78
Kent and Brydon's Darlington.						
New Raby 1901	11·41	10·63	0·78	11·02	11·10	−0·08
Portrack Grange...... 1902	11·13	11·07	0·06	11·10	11·48	−0·38
Grange Hill 1902	11·44	11·53	0·09	11·48	12·07	−0·59
Cleatlam 1902	12·60	12·10	0·50	12·35	12·58	−0·23
New Raby 1902	12·80	12·61	0·19	12·70	12·85	−0·15
Average for Durham						−0·29
Cockle Park 1901	10·41	9·94	0·47	10·18	10·32	−0·14
Eshott 1902	12·56	12·55	0·01	12·56	13·16	−0·60
Cockle Park 1902	11·76	11·99	0·23	11·87	11·93	−0·06
Cockle Park 1903	10·77	10·98	0·21	10·87	11·67	−0·80
Cockle Park 1904	14·90	15·28	0·38	15·09	14·96	+0·13
Average for Northumberland						−0·29
,, North of England, all results						−0·29
,, ,, ,, ,, less highest						−0·34
,, ,, ,, ,, ,, lowest						−0·23

* See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 + s + f	Variety factor
Kent and Brydon's XL All.				*A*	*	*v*
Cockle Park 1900	10·55	10·39	0·16	10·47	11·43	−0·96
Cockle Park 1901	9·69	10·15	0·46	9·92	10·32	−0·40
Riffington 1902	12·46	11·62	0·84	12·04	12·91	−0·87
Cockle Park 1902	11·22	11·25	0·03	11·23	11·93	−0·70
Cockle Park 1902	11·62	11·53	0·09	11·58	11·93	−0·35
Cockle Park 1903	11·17	11·44	0·27	11·30	11·67	−0·37
Eshott 1903	11·53	11·30	0·23	11·41	12·12	−0·71
Eshott 1903	10·91	11·36	0·45	11·13	12·12	−0·99
Average for Northumberland						−0·67
New Raby 1901	9·96	10·93	0·97	10·44	11·10	−0·66
Neasham Grange ... 1902	11·72	11·82	0·10	11·77	12·10	−0·33
Sherburn Colliery .. 1902	12·30	12·06	0·24	12·18	11·99	+0·19
Cleatlam 1902	12·10	11·69	0·41	11·90	12·58	−0·68
New Raby 1902	12·50	12·22	0·28	12·36	12·85	−0·49
Denton Grange 1903	12·22	11·80	0·42	12·01	13·03	−1·02
Portrack Grange 1903	10·65	10·75	0·10	10·70	11·08	−0·38
New Raby 1903	10·52	10·86	0·34	10·69	11·25	−0·56
New Raby 1903	10·82	10·43	0·39	10·63	11·25	−0·62
Sherburn Colliery ... 1903	11·00	11·40	0·40	11·20	12·15	−0·95
Average for Durham						−0·55
,, North of England, all results						−0·60
,, ,, ,, ,, less highest						−0·65
,, ,, ,, ,, ,, lowest						−0·58
Sutton's Crimson King.						
Cockle Park 1900	11·33	11·63	0·30	11·48	11·43	+0·05
Cockle Park 1901	10·59	10·34	0·25	10·47	10·32	+0·15
Riffington 1902	12·25	12·50	0·25	12·37	12·91	−0·54
Cockle Park 1902	11·61	11·52	0·09	11·57	11·93	−0·36
Cockle Park 1903	11·06	11·38	0·32	11·22	11·67	−0·45
Cockle Park 1904	14·61	13·89	0·72	14·25	14·96	−0·71
Neasham Grange ... 1902	11·60	11·68	0·08	11·64	12·10	−0·46
Sherburn Colliery ... 1902	11·22	11·68	0·46	11·45	11·99	−0·54
Grange Hill 1902	11·60	11·93	0·33	11·76	12·07	−0·31
Average for North of England, all results						−0·35
,, ,, ,, ,, less highest						−0·41
,, ,, ,, ,, ,, lowest						−0·31
Webb's New Arctic.						
Cockle Park 1900	11·62	11·92	0·30	11·77	11·43	+0·34
Cockle Park 1901	10·82	10·92	0·10	10·87	10·32	+0·57
Cockle Park 1902	12·32	12·46	0·14	12·39	11·93	+0·46
Cockle Park 1902	12·21	12·23	0·02	12·22	11·93	+0·29
Cockle Park 1903	11·14	11·15	0·01	11·14	11·67	−0·53
Eshott 1903	11·99	11·68	0·31	11·83	12·12	−0·29
Eshott 1903	12·13	12·38	0·25	12·25	12·12	+0·13
Cockle Park 1904	15·02	15·38	0·36	15·20	14·96	+0·24
Average for Northumberland						+0·15

* See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 +s +f	Variety factor
				A	*	v
Webb's New Arctic.						
Kelloe Hall 1902	12·57	12·67	0·10	12·62	12·14	+0·48
Grange Hill 1902	11·91	12·14	0·23	12·02	12·07	−0·05
Red Barns 1902	12·78	12·80	0·02	12·79	12·33	+0·46
Billingham 1902	13·65	13·60	0·05	13·62	13·15	+0·47
Denton Grange 1903	13·35	13·28	0·07	13·31	13·03	+0·28
Portrack Grange...... 1903	10·90	10·95	0·05	10·92	11·08	−0·16
Sherburn Colliery ... 1903	12·71	12·03	0·68	12·37	12·15	+0·22
Average for Durham..........						+0·24
,, North of England, all results						+0·19
,, ,, ,, ,, less highest						+0·17
,, ,, ,, ,, ,, lowest						+0·25
Webb's Imperial.						
Cockle Park 1900	12·25	11·93	0·32	12·09	11·43	+0·66
Cockle Park 1903	11·58	11·99	0·41	11·78	11·67	+0·11
Eshott 1903	11·79	11·86	0·07	11·83	12·12	−0·29
Sherburn Colliery ... 1903	12·25	12·38	0·13	12·32	12·15	+0·17
Eshott 1903	12·75	12·75	0·00	12·75	12·12	+0·63
Average for North of England, all results						+0·26
,, ,, ,, ,, less highest						+0·16
,, ,, ,, ,, ,, lowest						+0·39

* See Tables III and VI, also pp. 96 and 98.

TOWN STABLE MANURE: ITS CHEMICAL COMPOSITION AND THE CHANGES IT UNDERGOES ON KEEPING.

By BERNARD DYER, D.Sc., F.I.C.

THE use of town stable manure enters so largely into the economy of farms, and especially market-gardens, situated within fairly easy distance of London or other large cities, that it is somewhat curious that but little information has been published in this country as to its chemical composition. In fact, with the exception of a couple of analyses made by myself as long ago as 1889, which were published at the time in the *Mark Lane Express*, and subsequently reprinted in Aikman's book on "Manures and Manuring," I do not remember to have seen any analyses of London manure. The samples which were the subject of these analyses were collected from a very limited number of stables, some of which were littered with peat moss and others with straw, the object at the moment being to compare the manure produced with the two kinds of litter. I have more recently however made some fairly full analyses of two more representative samples of London manure, but before proceeding to give these it may be desirable to reprint in this place, for future reference, the old analyses just mentioned.

ANALYSES OF STABLE MANURE—1889.

	Manure made with Peat litter		Manure made with Straw litter	
Water ...		77·84		70·03
Organic matter, &c. (loss on ignition) ...		18·02		24·28
*Phosphoric Acid ...		0·37		0·48
Lime...		0·33		0·70
Potash ...		1·02		0·59
Magnesia, Soda, and other undetermined constituents ...		1·08		1·30
Siliceous Matter ...		1·34		2·62
		100·00		100·00
*Equal to Tribasic Phosphate of Lime ...		0·80		1·04
Total Nitrogen—				
Organic ...	0·37	0·88	0·52	0·62
Ammoniacal and Nitric ...	0·51		0·10	
Equal to Ammonia ...		1·07		0·75

If these results are calculated to the dry state we get:

	Manure made with Peat litter	Manure made with Straw litter
Organic Matter, &c. (loss on ignition) ...	81·12	82·36
*Phosphoric Acid ...	1·69	1·38
Lime ...	1·50	2·26
Potash ...	4·50	2·09
Magnesia, Soda, and other undetermined constituents ...	5·20	3·86
Siliceous Matter ...	5·99	8·05
	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	3·69	3·01
Total Nitrogen—		
Organic ...	1·67 } 3·93	2·10 } 2·51
Ammoniacal and Nitric ...	2·26 }	0·41 }
Equal to Ammonia ...	4·80	3·05

The comparatively recent analyses which I have made were in both cases analyses of what may be taken as representative samples of fresh London manure, consisting of peat-made manure and straw-made manure mixed. One sample was drawn from a consignment delivered in Kent and one from a consignment delivered in the Midlands. In each case samples were taken from a great many parts of the delivery and thoroughly mixed together, a fair sample of the resulting mixture being submitted to analysis. The results were as follows:

ANALYSES OF REPRESENTATIVE SAMPLES OF FRESH LONDON STABLE MANURE (PEAT MANURE AND STRAW MANURE MIXED)—1903.

	No. 1	No. 2	Average
Moisture ...	76·09	61·98	69·04
Organic Matter, &c. (loss on ignition) ...	19·30	26·37	22·82
*Phosphoric Acid...	0·33	0·45	0·39
Lime ...	0·55	1·28	0·92
Potash ...	0·45	0·58	0·51
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	0·69	2·70	1·70
Siliceous Matter (mainly sand) ...	2·59	6·64	4·62
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	0·72	0·98	0·85
Total Nitrogen—			
Soluble ...	0·08 } 0·54	0·08 } 0·70	0·08 } 0·62
Insoluble ...	0·46 }	0·62 }	0·54 }
Equal to Ammonia—			
Soluble ...	0·10 } 0·66	0·10 } 0·85	0·10 } 0·76
Insoluble ...	0·56 }	0·75 }	0·66 }

COMPOSITION OF ABOVE SAMPLES CALCULATED TO THE DRY STATE.

	No. 1	No. 2	Average
Organic Matter, &c. (loss on ignition) ...	80·70	69·36	75·03
*Phosphoric Acid...	1·38	1·17	1·27
Lime	2·29	3·38	2·84
Potash	1·90	1·54	1·72
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	2·90	7·08	4·99
Siliceous Matter (mainly sand)	10·83	17·47	14·15
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	3·01	2·55	2·78
Total Nitrogen—			
Soluble	0·36 } 2·27	0·21 } 1·84	0·28 } 2·05
Insoluble	1·91	1·63	1·77
Equal to Ammonia—			
Soluble	0·44 } 2·76	0·25 } 2·23	0·34 } 2·49
Insoluble	2·32	1·98	2·15

Sample No. 1 probably contains as much moisture as one would expect to find in stable manure which had not been intentionally watered to increase its weight; while sample No. 2 is somewhat drier than is often the case.

The analyses which now follow are analyses of samples of London stable manure taken in February from stocks which had been stored in heaps on a farm since the previous summer.

ANALYSES OF SAMPLES OF OLD LONDON MANURE AFTER STORING IN LARGE HEAPS IN OPEN FIELD FROM SUMMER TO SPRING.

	A	*B*	*C*
Moisture	53·83	61·88	52·89
Organic Matter, &c. (loss on ignition) ...	17·46	21·98	22·98
*Phosphoric Acid...	0·49	0·56	0·66
Lime	1·41	1·20	1·72
Potash	0·58	0·65	0·80
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	3·35	2·16	3·38
Siliceous Matter (mainly sand)	22·88	11·57	17·57
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	1·08	1·22	1·44
Total Nitrogen—			
Soluble	0·06 } 0·64	0·08 } 0·76	0·10 } 0·89
Insoluble	0·58	0·68	0·79
Equal to Ammonia—			
Soluble	0·08 } 0·78	0·10 } 0·92	0·12 } 1·08
Insoluble	0·70	0·82	0·96

COMPOSITION OF ABOVE SAMPLES CALCULATED TO THE DRY STATE.

	A	*B*	*C*
Organic Matter, &c. (loss on ignition) ...	37·81	57·66	48·78
*Phosphoric Acid...	1·07	1·47	1·40
Lime	3·05	3·16	3·66
Potash	1·25	1·70	1·70
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	7·27	5·66	7·17
Siliceous Matter (mainly sand)	49·55	30·35	37·29
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	2·34	3·21	3·06
Total Nitrogen—			
Soluble	0·13 } 1·39	0·21 } 2·00	0·21 } 1·89
Insoluble	1·26	1·79	1·68
Equal to Ammonia—			
Soluble	0·16 } 1·69	0·26 } 2·43	0·26 } 2·30
Insoluble	1·53	2·17	2·04

The samples obviously contain an unduly large quantity of sand. This, however, was not earth which had found its way into the dung from the fields in which the heaps were situated. The samples represented a very large mass of manure which had not been mixed with soil during the making of the heaps, and the sand was in each case found distributed throughout the mass. I concluded that a large proportion of road scrapings had probably been included in the manure. If this was not the case, sand or gravel must have been deliberately mixed with it. I calculated that the three batches of manure represented probably contained, in the original condition in which the manure was delivered, from 8 per cent. to 18 per cent. of sand. It is to be hoped, in the interests of those who purchase large quantities of London manure, that such extensive admixtures with sand are not frequent.

These observations as to sand are, however, subsidiary to the main interest of the analyses, which lies in the information to be derived from them as to the extent to which losses of fertilising matter have taken place during storage. As no analyses had been made of the actual manure before it was put into the heaps, the amount of such losses can only be arrived at by a process of inference. I have endeavoured to make an approximate computation of the nitrogenous losses by considering the ratio of phosphoric acid to residual soluble and insoluble nitrogen, and have accordingly calculated, in the case of the two average samples of fresh London manure, the ratio of phosphoric acid to total, soluble and insoluble nitrogen:

FRESH LONDON MANURE.

		No. 1	No. 2	Average
$\frac{\text{Phosphoric Acid}}{\text{Total Nitrogen}}$	=	$\frac{100}{164}$	$\frac{100}{157}$	$\frac{100}{161}$
$\frac{\text{Phosphoric Acid}}{\text{Soluble Nitrogen}}$	=	$\frac{100}{24}$	$\frac{100}{18}$	$\frac{100}{21}$
$\frac{\text{Phosphoric Acid}}{\text{Insoluble Nitrogen}}$	=	$\frac{100}{140}$	$\frac{100}{138}$	$\frac{100}{138}$

In the three samples of manure which had been kept from summer to spring in heaps we find the following ratios:

OLD LONDON MANURE.

		A	*B*	*C*
$\frac{\text{Phosphoric Acid}}{\text{Total Nitrogen}}$	=	$\frac{100}{131}$	$\frac{100}{136}$	$\frac{100}{135}$
$\frac{\text{Phosphoric Acid}}{\text{Soluble Nitrogen}}$	=	$\frac{100}{12}$	$\frac{100}{14}$	$\frac{100}{15}$
$\frac{\text{Phosphoric Acid}}{\text{Insoluble Nitrogen}}$	=	$\frac{100}{118}$	$\frac{100}{121}$	$\frac{100}{120}$

If it be assumed that the samples of old manure would have shown originally, in the fresh state, ratios similar to those found for the samples of fresh London manure, the difference between the ratios will afford material for calculating the losses which have taken place by fermentation in the heap.

The average ratio of the two fresh samples being taken as a basis, the losses would be as follows:

	A	*B*	*C*
Loss of original Total Nitrogen	19 per cent. (or say, roughly, one-fifth)	15 per cent. (or say, roughly, one-sixth)	15 per cent. (or say, roughly, one-sixth)
Loss of original Soluble Nitrogen	42 per cent. (or say, roughly, two-fifths)	30 per cent. (or say, roughly, one-third)	27 per cent. (or say, roughly, one-fourth)
Loss of original Insoluble Nitrogen	15 per cent. (or say, roughly, one-sixth)	13 per cent. (or say, roughly, one-eighth)	14 per cent. (or say, roughly, one-eighth)

The 1889 analyses are not comparable in all their details with the more recent ones, but it may be observed that in the old analyses the ratios of phosphoric acid to total nitrogen were $\frac{100}{238}$ for the peat manure and $\frac{100}{129}$ for the straw manure, the mean of the ratios for the peat manure and the straw manure being $\frac{100}{184}$. This mean ratio does not differ very much from that shown by the much more representative samples analysed later.

It may be added that the ratio of total "organic matter" to phosphoric acid in the two samples of fresh dung is respectively 58 : 1 and 59 : 1. In the three samples of manure that had been rotted down in the heaps, the ratio of organic matter to phosphoric acid was respectively 35 : 1, 39 : 1, and 35 : 1. It would thus appear that roughly speaking something like 40 per cent. of the organic matter disappeared in the process of fermentation, but the estimate can only be an approximation, because the item "organic matter" includes any water of hydration that may have been associated with the road scrapings, etc. Possibly the loss of actual organic matter may have been even greater.

London stable manure owes no small part of its practical value to the organic matter contained in it. The useful functions of this organic matter—whether for light or for heavy soils—need not be enlarged upon here; but since so large a diminution of the organic matter occurs in the heap it would seem to be good policy, quite apart from the question of loss of nitrogen, to apply the manure to the soil in as fresh a state as may be consistent with convenience and good farming.

SOIL ANALYSIS AS A GUIDE TO THE MANURIAL TREATMENT OF POOR PASTURES.

By T. B. WOOD, M.A., *Reader in Agricultural Chemistry*,

AND R. A. BERRY, F.I.C., *Assistant Chemist, Agricultural Department, Cambridge University.*

DURING the last five years the Cambridge University Department of Agriculture has been associated with H. M. Board of Agriculture, and with the County Councils of Cambridge, Essex, Norfolk, and Northampton, in carrying out a number of experiments on the improvement of poor pastures. The improvement has been measured by the increase in live-weight of sheep grazing the variously treated plots, and the results have in many cases been so good that an examination of all the soils has been made in order if possible to classify them, so that definite information might be available as to the kind of soil on which poor pastures might be capable of improvement by manuring.

Accordingly, samples of soil have been obtained from each station, and in many cases from each plot, and analysed chemically and mechanically, and in the following pages an attempt is made to collate the results of the field experiments with the analytical figures in order to see how far examination of a soil in the laboratory may indicate the best treatment to adopt.

The experiments, of which the agricultural results are given in Middleton's paper on *The Improvement of Poor Pastures* (see pp. 122—145), were carried out at the following stations:

CRANSLEY—Northants. Boulder clay soil.
HATLEY—Cambridge. Boulder clay soil.
YELDHAM—Essex. Boulder clay soil.
TROWSE—Norfolk. Sandy soil.

In addition to these four stations we are able to give the figures for two others:

COCKLE PARK—Northumberland. Boulder clay soil.
SEVINGTON—Hampshire. Sticky soil on chalk.

The figures for Cockle Park are taken from Somerville's "Five years' work at the Northumberland County Farm," and from the Annual Reports of the Durham College of Science; those for Sevington from the *Journal* of the Bath and West of England Society, 1903–4.

The analyses, except some of those for Cockle Park and some for Yeldham, are our own. The Cockle Park analyses are acknowledged above. For those of Yeldham we are indebted to Mr T. S. Dymond, F.I.C., of the Essex County laboratories, Chelmsford.

In our own work we have adopted for the chemical analysis the method agreed upon by the Agricultural Education Association, and described by A. D. Hall[1]; and for the mechanical analyses the method described also by Hall[2].

In the following tables the figures indicating the result of the various manures are calculated as follows:—The live-weight increases on each plot are averaged for the first three years after the application of the manures, except at Trowse, where the experiment could only be continued for two years. The average live-weight increase on the unmanured plot is then taken as 100, and the increase produced by each manure is calculated as a percentage of the increase on the unmanured plot.

Absolute increases are of course greater in good, than in bad seasons, but percentage increases do not vary nearly so much, as a good season increases the produce on both unmanured and manured plots. Percentage live-weight increase calculated thus, and averaged for three years, should give a reliable basis of comparison.

PHOSPHATES.

The most notable result of the experiments from the agricultural point of view is the very great improvement in the feeding value of the pasture produced by the application of a large dressing of basic slag. In the following table the figures showing this improvement, as average percentage live-weight increase, are set out side by side with the percentages of total and citric acid soluble phosphoric acid in the soils.

[1] *The Analyst*, November, 1900.
[2] *J. Chem. Soc.* 1904, 950.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average °/₀ live-wt. increase due to ½ ton basic slag*	240	233	127	106	38	−2
Percentage in soil of phosphoric acid (P_2O_5) sol. in strong hydrochloric acid	0·15	0·07	0·33	0·12	0·18	0·18
Percentage in soil of phosphoric acid (P_2O_5) sol. in 1 °/₀ citric acid	0·011	0·005	0·014	0·013	0·013	0·041

* Containing 200 lbs. phosphoric acid.

It is evident at once that only one of the soils can be called deficient in total phosphoric acid, namely Cockle Park, and only one soil, Hatley, exceptionally rich in that substance. A determination of the total phosphoric acid in the soil at Cockle Park indicates that no treatment could really improve the pasture which did not include the application of phosphatic manure. At Hatley, however, the percentage of total phosphoric acid clearly indicates that phosphate is not required, and the indication is entirely wrong, for basic slag has given a very profitable improvement. No clear indication can be drawn from the analytical figures for total phosphoric acid at the other stations. Determination of the total phosphoric acid gives a correct indication at Cockle Park, an incorrect one at Hatley, and fails to indicate one way or other at the other four stations.

A determination of the citric acid soluble phosphoric acid gives better results, for it again suggests the right treatment for Cockle Park, and shows that phosphate is not needed at Trowse. The percentages at the other four stations are just above Dyer's limit of 0·01 per cent.[1], and therefore suggest that phosphatic manuring is hardly needed. In three of the four cases, however, basic slag has made a great improvement, and quite a distinct one at the fourth station. For pasture soils, therefore, it appears as Hall suggests[2] that this limit of 0·01 per cent. needs revising. Enough information is not to hand at present, but the above figures appear to suggest that phosphates may be expected to give distinct results on pasture soils containing less than 0·02 per cent. phosphoric acid soluble in 1 per cent. citric acid, provided of course that other conditions are suitable for the phosphates to act. The necessity for raising the limit for citric acid soluble phosphoric acid in pasture soils is probably that citric acid dissolves organic matter, including organic phosphorus, if the soil is rich in humus. Probably the limit for

[1] *J. Chem. Soc.* 1894, 115, and *Phil. Trans.* 1901, 235.
[2] *J. Chem. Soc.* 1902, 117.

peaty soils should be higher still, for peats from the Isle of Ely, which respond very profitably to phosphatic manuring, yield as much as 0·05 per cent. phosphoric acid to 1 per cent. citric acid solution[1].

The analytical figures even for the citric acid soluble phosphoric acid do not come in the order indicated by the results with the sheep, but this can hardly be expected when we consider the indirect manner in which basic slag acts on the mixed herbage of a pasture, as shown by Middleton. (See p. 134.)

LIME AND CHALK.

The percentage of lime in a soil, and especially perhaps the percentage of calcium carbonate, may be expected to indicate, (1) if the soil needs liming, (2) whether basic slag or superphosphate may be expected to give the better result.

The figures bearing on these points are given in the following table. The amounts of basic slag and superphosphate each supplied 100 lbs. phosphoric acid per acre.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average % live-wt. increase due to 4 tons lime	—	4	—	26	3	—
Average % live-wt. increase due to 5 cwt. basic slag ...	106	96	95	53	24	-2
Average % live-wt. increase due to 7 cwt. super.........	62	91	85	47	30	-14
Percentage CaO in the soil...	1·64	0·69	1·15	0·63	2·87	1·36
Percentage $CaCO_3$ in the soil	1·30	0·59	0·91	0·27	4·20	1·90

As regards liming, analysis indicates only the Cransley soil as deficient in lime, and especially in calcium carbonate, and the indication is valuable, for it is only at Cransley that liming has given any appreciable effect. The effect is, however, still too small to be profitable, and the limit for calcium carbonate below which liming may be expected to be profitable is therefore probably below 0·25 per cent. Leaving out Trowse, for reasons which will be pointed out later, basic slag has given a better return than superphosphate at all the stations except Sevington, where the percentage of chalk is very high, 4·20 per

[1] *Annual Report, Cambridge and Counties Agricultural Education Scheme*, 1898.

cent. This appears to indicate that basic slag is a more suitable manure than superphosphate for poor pastures, unless there is a very high percentage of chalk in the soil.

POTASH.

In the following table are given the results of potash manuring, and the percentages of potash in the soils. The former are calculated by subtracting from the live-weight increases produced by potash applied with phosphate that produced by the same quantity of phosphate applied alone.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average % live-wt. increase due to potash	—	27	—	43	-7	20
Percentage in soil of K_2O soluble in HCl	0·52	0·50	0·80	0·57	0·55	0·13
Percentage in soil of K_2O soluble in citric acid 1 %	0·010	0·013	0·009	0·008	0·008	0·007

The figures for potash soluble in hydrochloric acid show exactly what might be expected—plenty of "total" potash in all the heavy soils, and a deficiency in the sandy soil of Trowse.

The figures for citric soluble potash are all low, the highest, Cockle Park, being only very slightly above the limit at which potash manuring may be expected to give distinct results[1]. The live-weight increases agree very well with the analytical figures for potash soluble in citric acid. At three of the four stations where potash was applied it has given a distinct increase. At Sevington the failure of potash is probably due to the fact that the land produced too much coarse grass in the first year of the experiment, and the sheep were consequently unable to eat it down. (See p. 130.)

NITROGEN.

Some of the plots received ammonium sulphate or sodium nitrate in addition to phosphates, and although nitrogenous manures cannot be expected to give good results on pastures when used in this way, it may be worth while to give the figures.

[1] Dyer, *Phil. Trans.* 1901, 235.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average °/₀ live-wt. increase due to Nitrogen	28	14	—	33	-15	0
Percentage of Nitrogen in soil	0·19	0·20	0·25	0·30	0·21	0·13

The figures show that a determination of nitrogen in a pasture soil gives no indication as to the effect of nitrogenous manuring. The effect of nitrogen has nowhere been great, and on inspecting the plots one reason is seen to be that it produces increased growth of grasses, interfering with the spread of clovers which the phosphates ought to produce in order that the pasture may be improved. (See p. 139.)

MECHANICAL ANALYSES.

Mechanical analyses have been made of all the soils, and the results are given in the following table side by side with the percentage live-weight increase produced by 10 cwt. basic slag.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Percentage in soil—						
Water	3·2	1·8	3·5	4·5	2·7	1·2
Organic matter	6·0	9·7	9·7	11·0	7·9	5·0
Stones—diameter over 3 mm.	—	0·6	3·0	2·1	11·8	10·7
Particles						
diameter 3 mm.—1 mm.	0	-	1·2	1·0	1·0	2·7
,, 1 ,, — ·2 ,,	26·3	23·3	20·5	7·4	5·9	60·0
,, ·2 ,, — ·04 ,,	23·9	25·2	13·0	15·0	16·1	11·0
,, ·04 ,, — ·01 ,,	11·5	10·6	11·1	11·5	18·8	3·6
,, ·01 ,, — ·004 ,,	7·2	9·6	7·8	9·8	7·1	0·7
,, ·004 ,, — ·002 ,,	1·4	2·3	9·5	6·1	6·4	0·7
,, ·002 ,, and under...	15·0	11·9	18·7	25·8	18·2	0·3
Percentage live-wt. increase due to ½ ton basic slag	240	233	127	106	38	-2

Inspection of the above table shows that the Trowse soil stands apart from all the others. It contains 60 per cent. of sand and only traces of the finer particles, and is of such coarse texture that it is unable, except when the summer rainfall is very great, to supply the herbage with enough water. Under these conditions the crop is limited

rather by the supply of water than by the amount of available plant food, and manurial treatment is therefore without effect. This is confirmed by the difference in the live-weight increase of the sheep on the cake-fed plot in 1901 and 1902. In the former year when the rainfall in May and June was about 2 inches, the sheep only gained 108 lbs., whilst in 1902 with 6 inches rainfall in the same period the sheep gained over three times as much. On such land, where rainfall is the predominant factor in determining the crop, manurial treatment for pastures must be comparatively ineffective.

Of the other soils, Cockle Park and Yeldham, which contain distinctly more sand and less clay, and approximate most nearly to a mixed soil, have reacted best to manuring, but this may in the former be due to its deficiency in phosphate. Still Cransley and Sevington with very little sand and much more clay have not reacted so well to manuring, and Hatley is intermediate both in content of sand and clay, and in reaction to basic slag.

It would appear therefore that while manures fail to improve pasture on very sandy soils owing to deficient water supply, a certain amount of sandy particles must be present in the soil to prevent the surface from baking hard and cracking.

Summary.

Summarising the above comparisons between soil analyses and results of manuring, the following conclusions are arrived at:

That except in extreme cases the determination of the percentages of "total" nitrogen, phosphoric acid, potash, and lime, in a soil does not give reliable indications as to the possibility of improving the pasture by manuring.

That determination of the percentage of phosphoric acid soluble in 1 per cent. citric acid solution does generally give reliable indications as to the probable success of phosphatic manuring, provided that for pasture soils the limit below which "available" phosphoric acid may be considered as deficient is fixed as high as 0·02 per cent.

That potash manuring is suggested as likely to give distinct results if the soil contains not more than 0·01 per cent. of potash soluble in 1 per cent. citric acid solution.

That liming is not indicated as likely to be profitable unless the soil contains certainly less than 0·25 per cent. of chalk.

That basic slag is nearly always a better source of phosphoric acid for pastures than superphosphate, unless perhaps when the soil contains an exceptionally high percentage of chalk.

That pastures are not likely to be improved by manuring unless their soil contains fair proportions of both large and small particles, and that the effect of manures is greater the more regularly the various grades of different sized particles are represented in the constitution of the soil.

Determinations of citric acid soluble phosphoric acid and potash, and of calcium carbonate, and mechanical analysis of the soil, together with careful observations of the herbage which the land in its unmanured condition is producing, may be expected to indicate clearly those soils which are likely to be improved for pasturage by manuring with phosphates and potash.

THE IMPROVEMENT OF POOR PASTURES.

By T. H. MIDDLETON, M.A.,

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DURING the second half of the 19th century it is probable that between four and five million acres of the poorest arable land of England reverted from corn-growing to grass. Since 1872 the increase in grass land has been over three million acres, and during the earlier period, for which statistics are not available, the fluctuating prices of wheat after 1850 must have been responsible for both the breaking up and laying down to grass of considerable areas of poor corn land[1].

A large proportion of the land laid down to grass since 1850 now forms grazing of the worst description. The surface has not become properly covered with vegetation, there is nothing that approaches a close turf, and the land bears no resemblance to what the farmer understands by the term old pasture. Within the past ten or fifteen years some of these poor grazing grounds have been improved by the use of basic slag and other manures, but one has only to study the *Agricultural Returns* to be convinced of the utterly unproductive state of most of the land converted into permanent pasture during the past half-century. This class of grass land is usually let at from 2*s*. 6*d*. to 7*s*. 6*d*. per acre, and the reluctance of owner or occupier to expend capital on such unremunerative property is not surprising. A mistake in dealing with these pastures is likely to be a costly mistake, and they are therefore left alone. But there is no real reason for thus neglecting them; no class of land responds with such certainty to proper treatment, and if landowners only realized the "inherent capabilities" locked up in these apparently barren soils, if they knew how easily the stores might be

[1] The average price of wheat in the United Kingdom for the years 1850–52 was 39*s*. 10*d*., for 1854–56, 72*s*. 1*d*., for 1863–65, 42*s*. 3*d*. See Blue-Book on British and Foreign Trade, 1903 [Cd. 1761], p. 121.

unlocked, if they understood the uses of the "key," two million acres of the most neglected and unproductive land in England could be turned into pastures of fair quality.

The principles underlying the proper treatment of poor pastures resting on clay or clay-loam soils have been demonstrated by the results of a series of six experiments conducted in different parts of England. These experiments are all of the same type and were designed by Dr Somerville. The first was laid down on Cockle Park, the experimental farm of the Northumberland County Council, in the winter of 1896–97, and the others were started in 1900 or 1901. Two of the later experiments were exact reproductions of the original at Cockle Park, and were arranged by H.M. Board of Agriculture; these were the experiments at Cransley, Northamptonshire, which is supervised by the Cambridge University Department of Agriculture for the Board of Agriculture and the County Council, and the experiment at Sevington, Hampshire, undertaken by the Bath and West of England Society. The management of the Hampshire experiment is in the hands of Mr Ashcroft, the Society's steward of experiments, and the analytical work has been done at Cambridge. The three remaining experiments are on a less extensive scale. They are supervised by the Cambridge University Department of Agriculture, and were laid out at East Hatley, Cambridgeshire; at Yeldham, Essex, in conjunction with the Agricultural Education Sub-Committee of the County Council; and at Trowse, Norfolk, in association with the Norfolk Chamber of Agriculture. Reports on these experiments have been published[1], but the collective results have not been discussed. In this paper a *résumé* of the results is given and the principles governing the rational treatment of poor pastures are explained.

In all the pasture experiments a suitable field of poor quality was selected and the land was then divided up into plots of $3\frac{1}{20}$ acres. Each plot was suitably fenced and was treated with the manures shown in Table I. The results of the manurial treatment have been ascertained by pasturing sheep on the plots for from 16 to 20 weeks in each season. Carefully selected sheep are weighed at the beginning of the

[1] See Annual Reports on Experiments Nos. VI, VII, VIII, and IX, issued by the Agricultural Depart. of the Durham College of Science; Somerville's "Five years' work at the Northumberland County Farm"; Reports on Cockle Park Experimental Farm, Nos. VI and VII, published by the Northumberland County Educ. Committee; Annual Reports on Experiments Nos. III, IV, and V, and Report on the Cransley Experiment, issued by Cambridge Univ. Agric. Dept.; Report on the Sevington Experiment, *Journal* of the Bath and West of England Society, 1903–04.

season, and also at the end of each month throughout the season, the total increase in live-weight is thus ascertained. The increase made shows the effects of the manures on the pastures. Sheep are kept in reserve in case of accidents to those grazing the plots, and precautions are taken to ensure that the records are not vitiated by the occurrence of illness in any of the animals.

A sub-plot of $\frac{1}{20}$th acre is fenced off before the sheep are put on the pastures and is cut for hay. A different plot is enclosed in each season, so that the grass cut may be a sample of the grass fed to sheep.

The Experimental Pastures.

Chemical and mechanical analyses of the soils have been made, and these are discussed in a paper by Wood and Berry (see pp. 114—121). A number of botanical analyses of the herbage have also been made. The most complete series is in connection with the experiment at Cockle Park, and references and figures will be found in the reports already cited.

It is outside the scope of the present paper to discuss the results of the botanical analyses, but before presenting the agricultural results an attempt will be made to indicate the general character of the herbage found on the different experimental pastures.

Cockle Park. A wretched pasture, laid down 30 or 40 years ago, and now worth from 2*s.* 6*d.* to 5*s.* per acre. The herbage at the time the experiment began consisted chiefly of bent-grass (*Agrostis* sp.) and heath-grass (*Triodia procumbens*). Associated with these in much smaller quantities were Yorkshire fog (*Holcus lanatus*), crested dogstail (*Cynosurus cristatus*), golden oat-grass (*Avena flavescens*), and cocksfoot (*Dactylis glomerata*). Irregularly scattered over the surface were patches of bird's-foot-trefoil (*Lotus corniculatus*) and medick (*Medicago lupulina*), and everywhere,—though so small as scarcely to enter into the edible herbage,—minute plants of white clover (*Trifolium repens*). The soil of the unmanured plot is nowhere closely covered, and though usually overspread by a coarse mat of dead bent, the surface soil is always visible. The bleached brown colour of the winter covering persists into June, when the fresh growth of bent gives a dull green tint to the surface; in August the purple panicles of bent distinguish the untreated plot from its neighbours, and a few weeks later the yellow tints of culm and blade give to the pasture a dull yellow-brown, very characteristic appearance. There is usually no lack of herbage on

the unmanured plot at Cockle Park, but it is so coarse in quality as to have little or no value for stock.

East Hatley. This field, which has been in grass for from 15 to 20 years, is not quite so poor as the last, but as the climate is less favourable than in the North of England, its value for grazing purposes is about the same. There is a good deal less white clover and more of the other Leguminosæ than at Cockle Park, and in some seasons bird's-foot-trefoil is very abundant. The grasses are well represented, and while bent predominates, crested dogstail, Yorkshire fog, meadow grasses (*Poa* sp.), timothy (*Phleum pratense*), and cocksfoot are fairly common. The soil is much more closely covered by vegetation than at Cockle Park, and the prominent defects of the pasture are that the herbage is late in growing, and that when it does begin to grow it rapidly becomes very coarse.

Yeldham. This field had been laid down to grass about 12 years when the experiment began. As sheep pasture it is perhaps the worst of the series. Medick is the predominant leguminous plant, and though white clover is common, the great increase produced by manures is due to the development of the former rather than of the latter. There is relatively little *Agrostis*, rye-grass (*Lolium perenne*) is common, but the characteristic grass on the unmanured land is crested dogstail. This grass developes few leaves, the hard culms soon shoot up, and the undergrowth dies, so that after the middle of July there is very little food for sheep. The soil, being unoccupied by grasses and clovers, is taken possession of by weeds. Cat's-ear (*Hypochœris*) and plantain (*Plantago*) are especially numerous.

Cransley. This pasture was laid down 20 to 30 years ago and is worth 4*s.* to 5*s.* per acre. The herbage is of the same type as at Yeldham, but the grasses do not seed so readily, and while, in August, the unmanured plot at Yeldham is covered by whitened dogstail culms, the corresponding Cransley plot is bare and closely grazed. Medick and suckling clover (*Trifolium minus*) are very common, white clover, though common, is much less abundant than at Cockle Park. While the Yeldham pasture contains a good deal of *Agrostis*, there is very little here. Among the grasses dogstail predominates, red fescue (*Festuca rubra*) is very abundant on the moister portions of the field and other small fescues are common all over the plots. Rye-grass and Yorkshire fog are also represented. A great deal of the surface is occupied by daisies (*Bellis*) and by hawkweeds (*Hieracium*).

Sevington. This pasture was laid down about 1892, and is worth

7*s.* to 10*s.* per acre. Ashcroft describes the herbage as even in character, "the plots varying more internally than one from another, except that Plots 9 and 10 have stronger tendency to a vigorous growth of top grass[1]." Both the chemical analysis, however, and the botanical separation of the herbage of 1901 indicate considerable variations from plot to plot, and these differences have somewhat affected the results. The pasture is of fair quality, and much better than those already described; medick is the chief leguminous plant, but white clover is common. Cocksfoot predominates among the grasses, and rye-grass, dogstail, and soft brome (*Bromus mollis*) are all abundant.

The botanical analysis of 1901 revealed a very unequal distribution of cocksfoot and medick over the plots. The figures were

	Dactylis	*Medicago*
Plots 1— 5	3—12 p.c.	35—49 p.c.
„ 7—10	59—69 „	10—13 „

The actual differences in the grazing qualities are much less than these figures suggest; a preliminary experiment made with sheep in 1900 showed on Plots 1—5, 70 lbs. increase per acre, and on Plots 7—10, 73 lbs. But under the influence of manures the natural differences have been accentuated, and when the writer visited the field in June, 1903, it was evident that the quantity of cocksfoot in the herbage of one side of the field, and especially in Plots 8—10, was injuriously affecting the quality of the pasturage.

Trowse. The five pastures described above all occupy clay or strong loam soils; at Trowse the soil is sandy, and as on all sandy soils the herbage varies greatly with the season. In 1902 the field was covered with dry, leafless brome-grass (*Bromus mollis*); very few other grasses were to be seen. The undergrowth was very poor, and with the exception of suckling clover, which was plentiful in parts of the field, the clovers were badly represented. The general appearance of the field in the middle of June was that of a meadow rather than that of a pasture.

We have then in the six poor pastures selected for experiment, types of herbage of a somewhat different character. Cockle Park represents those pastures in which bent-grass predominates among Gramineæ, and white clover among Leguminosæ. Cransley is typical of the numerous poor pastures occupied by such grasses as crested dogstail and the smaller fescues, and such leguminous plants as medick and

[1] Bath and West of England Society's *Journal*, 1903–04, p. 158.

suckling clover. At Sevington, associated with the same leguminous plants we have the stronger grasses, cocksfoot and rye-grass.

The Hatley and Yeldham pastures are intermediate types. The former between Cockle Park and Cransley, the latter between Cransley and Sevington.

At Yeldham, as at Cransley, crested dogstail and medick are the predominant plants. After manuring rye-grass and cocksfoot develop strongly and, as at Sevington, the grasses readily run to seed. Yeldham grows a good deal more bent-grass than Cransley, and in this respect is intermediate between Cransley and Hatley.

The pasture at Trowse stands quite by itself, and as the results at this station differ markedly from those obtained on the clay soils, consideration of them will be deferred until the results from the five remaining experimental pastures have been discussed.

MANURES AND RESULTS FOR THREE SEASONS.

The manurial treatment of each of the plots, together with the increase for the first three years, *in excess of the increase on untreated land* will be found in Table I. Before we attempt to draw conclusions from those figures, however, there are certain points to which attention must be directed.

The figures in the case of Plot 1 relate to a single year. During the first two seasons the sheep on this plot received oilcake. Feeding with oilcake was stopped in the third year, so that the effects of the residues might be tested. The results of the third season's grazing of this plot, which have been given in Table I, show that the residues have produced an appreciable increase on all the clay soils, and a marked effect at Cockle Park[1]. The influence of these residues on the pastures, however, was not favourable, some of the grasses were encouraged, but the improvement was temporary, and the change in the character of the herbage was not of a satisfactory kind.

Quicklime produced a small increase at Cransley on a soil very deficient in lime, but at Cockle Park and Sevington it was practically without effect.

Plots 3, 4, and 5 were treated respectively with 200 lbs. phosphoric

[1] There is reason to suspect, however, that this increase has been slightly exaggerated. Plot 1 occupies the part of the field nearest the homestead and, through stock lying upon it, was somewhat better than Plot 6 when the experiment was begun.

TABLE I. Pasture Experiments at Six Stations. Results of third season on Plot 1. On the other Plots the average results are given for the first three seasons (at Trowse for two seasons only). Results stated in terms of the Live-Weight Increase of Sheep *in excess of the Increase on the Unmanured Plot*. Grazing Plots 3 acres. Figures "per acre."

Plot	TREATMENT	Cockle Park, Northumberland	Cransley, Northamptonshire	Sevington, Hampshire	Hatley, Cambridgeshire	Yeldham, Essex	Trowse, Norfolk	Average of Cockle Park, Cransley and Sevington	Average of all stations except Trowse	Approximate Cost of Manures per Acre in terms of Increase	Annual Live-Weight Increase or Decrease at Cockle Park, Cransley, and Sevington, deducting cost of Manures
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1	Residue of Linseed or Cotton Cake fed in first two seasons	58	16	31	16	14	—	35	27	?	—
2	4 tons Quicklime in first season	2	14	4	—	—	—	7	—	64	−57
3	200 lbs. Phosphoric acid (P_2O_5) in about 10 cwt. Basic Slag in first season	107	56	44	85	68	−5	69	72	28	41
4	100 lbs. Phosphoric acid in about 5 cwt. Basic Slag in first season	44	28	28	64	30	—	33	39	14	19
5	100 lbs. Phosphoric acid in about 7 cwt. Superphosphate in first season	42	25	35	57	18	−22	34	35	19	15
7	Super. as for Plot 5 with 50 lbs. Potash (K_2O) in Sul. of Potash or Kainit in first and third seasons	54	47	27	—	—	9	43	—	36	7
8	Super. as for Plot 5 with about 10 cwt. ground Quicklime in first and third seasons	55	49	27	—	—	—	44	—	43	1
9	Super. as for Plot 5 with 14 lbs. Nitrogen in Sulphate of Ammonia in first and third seasons	48	42	17	—	26	—	36	—	35	1
10	100 lbs. Phosphoric acid and 14 lbs. Nitrogen in Dissolved Bones in first season	48	44	19	—	—	—	37	—	33	4

Notes. The average increase for the first three years on the unmanured plots was as follows:—Cockle Park 46 lbs., Cransley 53 lbs., Sevington 115 lbs., Hatley 67 lbs., Yeldham 30 lbs., Trowse 156 lbs. per acre.

The manures were applied in winter or early spring. The cost of the manures has been expressed in lbs. increase, and the net increase has been entered in the last column on the assumptions that live increase is worth 35*s.* per cwt., and that the entire cost of the manures is paid for in three years.

In the first two years the quantities of cake fed on Plot 1 were, per acre: Cockle Park and Sevington 5¼ cwt., and Cransley 6¾ cwt. Decorticated Cotton Cake; Hatley 5 cwt., and Yeldham 9½ cwt. Linseed Cake; Trowse 7½ cwt. mixed Linseed and Undecorticated Cotton Cake.

Plots 5 and 7 at Trowse received 200 lbs. Phosphoric Acid in Superphosphate.

Plot 9 at Yeldham received 20 lbs. Nitrogen in 1901 and 1902, and 40 lbs. in 1903.

acid per acre in basic slag, 100 lbs. in basic slag, and 100 lbs. in superphosphate. Although the influence of phosphatic manure is not usually marked until the second year, the average increase of the three seasons has been so great that the cost of the manures has been recovered two or three times over. At every station the larger of the two dressings of slag was most profitable, and at three out of five stations Plot 3 produced twice, or more than twice, the increase produced on Plot 4. This reversal of the law of "diminishing returns" is not accidental, and it indicates that the effect of the manure is not of the usual kind, but has to some extent been indirect. As a source of phosphates the cheaper and insoluble basic slag has equalled or surpassed superphosphate, except on the calcareous clay soil of Sevington.

At Yeldham the poor returns from superphosphate are probably accidental. The difference between Plots 4 and 5 was due to the results obtained in season 1902. In that year Plot 4 grew a much heavier crop of medick than Plot 5. In other respects the plots were similar. There is no reason to suppose that medick is more encouraged by basic slag than by superphosphate, for at Sevington, where medick is, as at Yeldham, the leading representative of the Leguminosæ, Plot 5 excelled Plot 4. Medick appears to be very easily affected by slight changes in soil and environment, and its distribution over a pasture is often irregular. In the case of Yeldham it is likely that this irregularity has caused the difference in the effects of basic slag and superphosphate[1].

At Cockle Park and also at Cransley the addition to superphosphate of a potash manure on Plot 7, of lime on Plot 8, and of nitrogenous manures on Plots 9 and 10, has increased the yield, while at Sevington there has been a decrease in every case. The figures for Plots 7 to 10 at the Northampton and Hampshire stations require explanation. A preliminary feeding experiment at both stations showed that in season 1900 the quality of the pastures was practically the same. The results of the preliminary test at Sevington have already been given (see p. 126). At Cransley the sheep on Plots 1-5 increased 54 lbs. per acre, while those on Plots 6—10 increased 51 lbs. But although the preliminary tests were satisfactory the fields prove not to be so uniform as at first appeared to be the case.

The two groups of plots at Cransley occupy different sides of a field, and the second group, from the slope of the surface is a little drier than

[1] A change in the slope of the field probably accounts for the irregular distribution of medick. The soil itself appears to be uniform.

the first. During the wet summers of 1902 and 1903 Plots 7 to 10 had a distinct advantage over Plot 5, and as the result of repeated inspections of the experiment in these seasons the writer has come to the conclusion that the effects attributed by the figures in Table I to the action of potash, lime, and ammonia at Cransley, are exaggerated by from 10 to 15 lbs.

At Sevington the quality of the herbage as sheep pasture appears gradually to deteriorate from Plots 5 to 10, and it is unlikely that the use of potash and lime has depressed the yield to the extent indicated in Table I. The deficits in Plots 7 and 8 as compared with Plot 5 are chiefly due to the poor results obtained from the potash and lime plots in 1901. In 1902 and 1903 the results from Plots 5, 7, and 8 were nearly the same (they averaged 169 lbs., 168 lbs., and 164 lbs. per acre increase respectively), and it is clear that the difference in 1901 was due more to the composition of the herbage (see p. 126) than to the manures.

With respect to Plots 9 and 10 it appears probable that nitrogenous manures have been directly injurious at Sevington (by causing the grasses to run to stem).

In the case of Cockle Park there have been no disturbing factors, and as in the writer's opinion the results from Plots 7–10 at Sevington are too low by about the same amount that those of Cransley are too high (10–15 lbs. per acre), the figures in the average column in Table I appear to him to represent the actual effects of the manures used on Plots 7–10.

With these explanations the following conclusions may be drawn from the figures given in Table I. The conclusions apply to pastures on clay soils in an impoverished state, and they cover a period of three years from the time that the work of improvement has been begun.

1. Phosphatic manures produce a highly profitable increase. A 10 cwt. dressing of basic slag is more profitable than a 5 cwt. dressing, and basic slag surpasses superphosphate. (Two of these conclusions apply not only to the average results but to every one of five stations situated in five counties representing the North, Midlands, East, and South of England. The third conclusion applies to four stations only; on the calcareous clay soil of Sevington superphosphate has been slightly more profitable than basic slag.)

2. Potash manures have been used at three stations in conjunction with superphosphate, and in two cases have considerably increased the yield. In one of these cases the increase has apparently left a profit, but reasons exist for thinking the profit doubtful, and on the whole evidence

it may be concluded that potash manures are seldom likely to be of importance on clay soils during the earlier stages of improvement.

3. The remarks made with respect to potash apply also to lime so far as the results stated in Table I are concerned, but further evidence exists, and will be given below, showing that lime has an important effect when used with superphosphate.

4. Nitrogenous manures have had a slight effect in increasing the pasturage, but they interfere with the action of phosphates, and their use during the early stages of improvement is to be strongly condemned.

5. In the absence of other manures the residues of oilcakes have considerably increased the pasturage, but as they increase grasses at the expense of the leguminous herbage these residues are likely to do more harm than good during the first two years after improvement has been begun.

RESULTS AT COCKLE PARK FROM THE FOURTH TO THE EIGHTH SEASON.

At the end of the third season those of the plots which originally received 100 lbs. phosphoric acid per acre had the dressing repeated. Except in one case we are not able to follow the effects of this treatment, for most of the experiments have only completed the fourth year; but at Cockle Park, which from the uniformity of its plots and the consistency of its results must be looked upon as the most satisfactory of all the experiments, we are fortunate in having a continuous record for eight years, and to this record we turn for further guidance in the management of poor pastures of this type.

Table II presents a summary of the results at Cockle Park for the eight seasons ending with 1904. The figures give the increase made by sheep *in excess of the increase on untreated land* for three periods, viz. 1897–99, 1900–02, 1903–04[1]. The increase for each period is the average annual increase. The general character of each of the eight seasons 1897–1904 is indicated by the increase made on Plot 6, which was unmanured. This increase was:

1897	37 lbs. per acre	1900	44 lbs. per acre	1903	41 lbs. per acre
1898	53 ,, ,,	1901	23 ,, ,,	1904	33 ,, ,,
1899	48 ,, ,,	1902	41 ,, ,,		
Average	46 ,, ,,	Average	36 ,, ,,	Average	37 ,, ,,

Average for eight years 40 lbs. per acre.

[1] For the figures for season 1904 the writer is indebted to Professor Gilchrist of the Armstrong College, Newcastle-on-Tyne.

TABLE II. Pasture Experiment at Cockle Park, Northumberland. Results for three years 1897–99, three years 1900–02, two years 1903–04, and eight years 1897–1904. The figures give the average Annual Live-Weight Increase made by Sheep *in excess of the increase on the unmanured plot.* The last Column gives the net Annual Increase obtained by deducting from the gross Increase, the Increase necessary to pay for the Manures. Grazing Plots 3 acres. Figures "per acre."

Plot	TREATMENT	Annual Live Increase during			Eight years 1897–1904		
		Three years 1897–99	Three years 1900–02	Two years 1903–04	Average Live Increase	Annual Cost of Manures in terms of Increase	Net Annual Live Increase or Decrease (−)
		lb.	lb.	lb.	lb.	lb.	lb.
1	Decorticated Cotton Cake fed on Plot, 1897, 1898, 1903, 1904, total, 16 cwt.	64	31	152	74	?	—
2	4 tons Quicklime, 1897 and again in 1903	2	20	13	12	40	−28
3	200 lbs. Phosphoric acid (P_2O_5) in Basic Slag in 1897, nothing since	107	85	55	86	9	77
4	100 lbs. Phosphoric acid in Basic Slag in 1897, and again in 1900	44	95	68	69	9	60
5	100 lbs. Phosphoric acid in Superphosphate in 1897, and again in 1900	42	90	47	61	14	47
7	Super. as for Plot 5 and 50 lbs. Potash (K_2O in Sulphate) in 1897, 1898 and 1903	54	92	60	70	25	45
8	Super. as for Plot 5 and 10 cwt. ground Quicklime in 1897, 1899 and 1903	55	120	72	83	28	55
9	Super. as for Plot 5 and 20 lbs. Nitrogen in Sul. Am. in 1897, 14 lbs. in 1899, 17 lbs. in 1900, and 17 lbs. in 1903	48	79	49	60	30	30
10	100 lbs. Phosphoric acid and 17 lbs. Nitrogen in Dissolved Bones in 1897 and again in 1900	48	88	57	65	26	39

Note. The prices of the Manures on which the figures in Column 7 are based, are the prices at Cockle Park. In Table I the prices of the Manures were the average prices at the different stations.

The cost of the manures has been expressed in terms of Increase and the net increase has been entered in the last column on the assumptions that live increase is worth 35*s*. per cwt. and that the entire cost of the manure is paid for in eight years.

In the light of further experience we may now review the conclusions come to on p. 130.

With respect to the phosphatic manures used on Plots 3, 4, and 5 the figures in Table II confirm the results in Table I. It is now clear, not only that the dressing of basic slag given to Plot 3 has been more profitable than that applied to Plot 4, but that by dividing the dressings of slag, and using half quantities at an interval of three years, the effect of the manure has been considerably reduced. (This point is of great practical importance.) At the end of eight years the superiority of basic slag over superphosphate is pronounced. At the end of the fifth season the increase on Plots 4 and 5 was equal, but during the past three years Plot 4 has rapidly improved its position.

The results obtained from potash manuring during the second period were disappointing. In 1902 however an improvement began. Plot 7 now grows clovers better than Plot 5, and it is clear that the latter plot is beginning to suffer from a lack of potash.

During the first three years Plot 3 attracted most notice but in the second and third periods Plot 8 (super. and lime) has been the most interesting, as well as the most productive plot in the field. It was most fortunate that the combination of manures here used found a place in the scheme, for by the action of lime on Plot 8 we are enabled to explain the whole effect of basic slag.

The influence of ground quicklime became marked in 1900, and was very striking in 1901 and 1902. The notable increase during these years was not, however, due to the action of lime on the Leguminosæ, but to its influence on the Gramineæ. The development of such grasses as crested dogstail, golden oat-grass, Yorkshire fog, cocksfoot and sweet vernal was astonishing; Plot 8 began to assume the appearance and character of a meadow, and difficulty was experienced in grazing it properly. In spite of some waste of grass, however, the sheep benefited greatly by the change, as the mixed character of the herbage prolonged the grazing season, and the grass came earlier in spring and persisted into the autumn. Plot 8 stood out conspicuously at two seasons—in spring, when it turned green before any of the other plots, and in July when the grasses were in flower.

The action of lime on the herbage of Plot 8 was obviously due to its effect on the organic matter accumulated in the surface soil by clover. Lime promoted the decomposition of this organic matter and thus aided the grasses by increasing the supply of nitrates.

The quicklime applied to Plot 2 has had little effect, because here

the lack of phosphates prevented the growth of clover, so that there has been no rapid accumulation of organic matter in the surface soil.

A slight improvement was noticeable in Plot 2 during the second period, and this may be attributed either to the gradual decomposition of intractable organic and mineral compounds under the influence of lime, or to the somewhat improved texture which lime would be likely to give the raw surface soil.

The further experience of cake-residues and of artificial nitrogenous manures gained on Plots 1, 9, and 10 at Cockle Park confirms the conclusion with respect to their value already stated (see p. 131).

INFLUENCE OF MANURES ON LEGUMINOSÆ AND ON GRAMINEÆ.

It is clear from a study of the results of these five pasture experiments that basic slag is the most useful of the manures tested, and that it ought to be employed liberally as on Plot 3, not in small dressings as on Plot 4. To those who are accustomed to use manures on arable land or on old pastures of good quality, and who have not followed the changes produced by basic slag in the herbage of poor clay soil pastures, the foregoing statement of results and conclusions will suggest many questions.

Why do phosphates produce so great and so rapid an increase? How can a 10 cwt. dressing of basic slag cause more than twice the increase produced by 5 cwt.? Why are two 5 cwt. dressings of slag inferior to a single 10 cwt. dressing? Why should slag and superphosphate produce nearly equal results for a time, and why should the soluble manure then fall behind? Why are nitrogenous manures injurious? These are some of the questions likely to be suggested by the experiments. A study of tables of figures will not supply answers, but the pastures themselves, when closely examined, clearly explain the action of the manures.

These poor worn-out soils furnish all the conditions necessary for the healthy and vigorous growth of Leguminosæ save one—a supply of phosphates. When phosphates are applied in manure a very rapid increase in the leguminous herbage takes place, and in a year or two a green carpet of white clover, or a loose tangled crop of medick covers the barren surface. A rapid improvement in the quality of the surface soil immediately sets in, the herbage is converted into manure by stock, roots open up and aërate the dense harsh sub-soil, organic matter accumulates, and atmospheric nitrogen is fixed by the nodule organisms. Thus because

of the extraordinary rapidity with which clover can grow and spread under favourable conditions, the soil becomes closely covered with vegetation until it bears some resemblance to the virgin state in which the plough found it, and is—by natural processes—enriched until it again possesses some of that fertility of which the plough robbed it.

Phosphates produce little or no direct effect on grasses, but as soon as clover has improved the surface soil grasses begin to spread. If at this stage the soil is supplied with lime (either the lime of basic slag, or quicklime) decomposition and nitrification go on rapidly and the grasses grow very quickly. As the result therefore of the action of phosphates on Leguminosæ, and of lime on the Gramineæ, we have at the end of three or four years a mixed herbage of fair quality covering the formerly impoverished pastures.

In the case of Cockle Park, Yeldham, and Cransley the 10 cwt. dressing of basic slag produced twice, or more than twice, the increase of the 5 cwt. dressing, because, apart from the lack of phosphates, the soil was capable of carrying a very heavy crop of clover or medick, and the larger dressing of manure enabled these plants to take full advantage of the favourable natural conditions. The stronger root development that followed the use of an ample supply of phosphoric acid enabled the plant to collect greater quantities of moisture, and to double or treble its growth.

Clovers appear to be as well suited by superphosphate as by basic slag, but the latter contains lime, which assists the grasses, and this is why Plot 4 has of late years surpassed Plot 5 at Cockle Park. The results obtained on Plot 8 show that the decline of Plot 5 cannot be entirely or even largely due to a more rapid exhaustion of the soluble, than of the insoluble phosphates.

Two separate 5 cwt. dressings of basic slag, such as were applied to Plot 4, are inferior to a single 10 cwt. dressing as used on Plot 3, because as a result of the first manuring grasses spring up in the pastures and come into competition with clovers. Clovers are unable to develop in the face of competition, and for this reason they do not benefit fully by a second application of manure. Since it is most desirable that clovers should have the fullest scope for development during the first two or three years, the use of any manure likely to stimulate grasses into immediate and rapid growth is to be condemned. Farmyard manure, sulphate of ammonia, and nitrate of soda should not be used until two years after phosphates have been applied.

That the presence of lime promoted the decomposition of organic

matter and acted as a nitrogenous manure at Cockle Park and Cransley, was quite evident both from the colour of the grasses in early spring and their subsequent development. So far as he has been able to judge from inspection of the plots the writer thinks that ground lime has had little direct effect on the clovers.

The opinions expressed respecting the influence of phosphates on clover and on the effects of the competition of grasses with clover, are based partly on evidence derived from inspection of the plots and partly on experiments.

As these two points are of great importance in explaining the action of phosphatic manures, the experimental evidence will be given.

In the winter of 1902–03 the writer was consulted about the improvement of a poor clay soil at Wendon Lofts in Essex. The general character of the pasture was that of the clay soils on which phosphates produce so marked an effect, but in this case a close search revealed no Leguminosæ; it was decided therefore not to apply phosphatic manures to the field; but a small area was set apart for an experiment. Plots were marked off and treated with basic slag, kainit, and lime in the end of January. The manures were used both alone and in combination. In March white clover seed at the rate of 12 lbs. per acre was sown on certain plots, so that the clover occupied both untreated land, and land previously manured with basic slag. Owing to the hard state of the surface the seed could not be harrowed in, and it was sprinkled on the surface and left. The wet summer of 1903 was favourable to the experiment, and in the autumn, although no effects of the manuring could be detected, the young clovers were found to have established themselves. In 1904 the results were very marked. None of the manures and none of the combinations of manures applied to the original soil produced any effect, but where clovers had been sown after the application of basic slag, there was the luxuriant growth which one expects in pastures where Leguminosæ are present. In the absence of basic slag the clover plants did not develop, but remained throughout the season in an impoverished state. From the Wendon Lofts experiment we may conclude that in the absence of Leguminosæ phosphatic manures will not increase the produce of poor clay pastures, at least during the first and second years after application.

That the enormous development of white clover which follows the use of basic slag is only possible on a soil unoccupied by grasses must

be evident to anyone who studies the habit of the clover plant. Where phosphates are abundant its growth for the first two or three years after manuring seems to be limited only by the quantity of moisture it can secure. The runners spread all over the surface, and rooting freely wherever the soil is bare the plant contrives to supply itself with an abundance of moisture on clay and heavy loam soils, even in moderately dry weather; but directly grasses spring up not only is the surface occupied so that clover-runners cannot root, but the surface is robbed of its moisture so that the plant cannot grow quickly. In ordinary seasons the long runners of white clover may always be found in the coarse tufts of grass which spring up on poor clay soil pastures, but towards the close of the past dry summer the writer searched in vain for runners in the grass tufts on three experimental pastures; the grasses had used up all the surface moisture, and clover had disappeared.

Basic slag seldom effects any great change on old pastures where there is a close turf, for the surface being already fully occupied clover cannot spread much. This manure is also likely to fail on poor, moist pastures which have become covered with a layer of partially decomposed vegetable matter, for until the peaty covering has been reduced by lime clover runners cannot root freely.

The effect of the competition of grasses on the progress of clover was very clearly shown by Plots 4 (basic slag) and 5 (superphosphate) at Cockle Park in seasons 1900–02. For five years, as has already been pointed out, these plots ran a very close race. At the end of the first three years Plot 4 was ahead of its rival. In 1900 however, after the second application of manure had been given, Plot 5 improved its position. This result was attributed to the soluble condition of the phosphate, and it was believed that Plot 5 would now begin to deteriorate; in 1901, however, it still further improved its position. As the season progressed a marked difference was observable in the herbage of the two plots which explained the improvement. On Plot 5 there was a fine healthy crop of white clover and the chief grass was bent, which owing to its loose, open habit of growth is clover's least formidable competitor[1]. On Plot 4, as the result of the action of the lime in the basic slag, crested dogstail, golden oat-grass, Yorkshire fog, and other grasses were much more numerous than on Plot 5, there was less bent-grass, and the clover plants though numerous

[1] In some respects *Agrostis*, by providing shelter in winter and spring, may be regarded as an ally.

were smaller and distinctly inferior to those on Plot 5[1]. In 1902 the clovers began to disappear, and as the gramineous herbage is inferior, Plot 5 has somewhat rapidly deteriorated of late years, but it is clear that the recovery in 1900 and 1901 was due to the fact that the grasses on Plot 5 did not then form so close a sward as they did on Plot 4.

The failure of phosphatic manures to improve the Trowse pasture was not due to the absence of Leguminosæ as at Wendon Lofts, but to the absence of a continuous and sufficient supply of moisture near the surface. On light soils occupied by grasses clover cannot produce long runners. When the conditions are favourable white clover may make runners a yard or more long, but on light soils they seldom exceed 6 to 12 inches. At Trowse the Leguminosæ, limited in their water supply, could not take advantage of the phosphates, and as it was evident that except in abnormally wet seasons the clover would never be able to benefit by, or to pay for the heavy dressings of phosphates so profitably employed on clay soils, the experiment was abandoned at the end of two years. The results from Plot 7 indicate indeed that it was a potash and not a phosphatic manure that was wanted on the Trowse soil, but large quantities of a potash manure would have been quite as inappropriate as heavy dressings of a phosphate, for on this pasture the vegetation is not of a kind that can absorb and utilize large quantities of manure. The building up must be gradual, and in improving it small dressings of mixed manures should be applied at frequent intervals.

Even on clay soils the season's rainfall is an important factor in the spread of clover, and occasionally on soils which crack much and become very dry on the surface phosphates may fail to produce their usual effects[2].

Absence of Leguminosæ at Wendon Lofts and of moisture at Trowse rendered phosphatic manures useless; there is a third cause of failure which may be noticed here. Some soils, especially medium or light loams, which might otherwise benefit by an application of phosphates, fail to respond because of a deficiency of potash. From the experiments described above it seems safe to conclude that clay soils will seldom fail at the outset for this particular reason, but sooner or later the

[1] The difference in the type of herbage on Plots 4 and 5 was very marked in July, 1901, and visitors to Tree Field expressed astonishment that the source of the phosphoric acid could exercise so great an influence on the appearance. At the same time the value of the two pastures for grazing purposes was very equal, and parties of farmers could never agree as to which was worth most.

[2] See Annual Report Camb. and Counties Agric. Education Scheme, 1898, p. 16.

available potash in the surface soil will become exhausted and the pasture will suffer. There is evidence that about the sixth season the absence of potash began to be felt by the clovers on Plot 5 at Cockle Park, and in another Northumberland experiment where basic slag in conjunction with kainit was very successful, and where kainit used alone was useless, basic slag began to lose its effect in the third season because of a lack of potash.

MANAGEMENT OF POOR PASTURES.

We are now in a position to lay down rules for the guidance of those who wish to improve poor pastures on clay soils.

In the great majority of these pastures Leguminosæ are numerous, and the first consideration must be the stimulating of the Leguminosæ, and especially of white clover, into active growth. The experiments clearly indicate that the greater the development of the clovers during the first year or two the greater and more lasting will be the improvement of the pastures. To obtain the best results it is essential that the clover should be enabled to make rapid growth before it has to face the competition of the grasses, and therefore the proper course is to apply as much phosphatic manure as the Leguminosæ present can utilize. In most cases when in doubt it is wise to apply less rather than more artificial manure than is likely to be required, but here it is best to err on the other side. Phosphates are not expensive, and every shilling's worth utilized by clovers in the first two years is likely to bring in a sevenfold return. The best quantity will of course vary under different conditions. When white clover is the leguminous plant, when bent is the predominant grass, and when the climate is moist, from 10 to 12 cwt. of basic slag per acre would be a suitable dressing. When medick, suckling clover and bird's-foot-trefoil represent the Leguminosæ, when the grasses are mixed, and when the climate is dry, from 7 to 10 cwt. of basic slag may be recommended. Under certain conditions superphosphate might prove superior to slag, but these conditions are not likely to occur often.

During the first two years any treatment calculated to strengthen the Gramineæ must be avoided; but after the first two or three years have passed the clovers will inevitably begin to diminish in quantity and grasses will spring up. If care be exercised a close turf will now begin to form and the barren field will gradually assume the appearance of an old pasture. Detailed directions cannot be given for the manage-

ment of the pasture at this stage; the treatment will vary in different cases. The aim must now be not to encourage clovers only, but to produce a mixed herbage. Many of the better grasses will be weak and the closest attention must be given to the grazing of the surface. If the young grasses are allowed to seed, or if they are too closely grazed, they may die off; and if coarse grasses, which are always present, are permitted to take possession an inferior pasture will result. When such grasses as bent and Yorkshire fog are allowed to cover the surface a close turf will not form, the opportunity of establishing better grasses in a soil enriched by clover residues will be lost, and an equally favourable opportunity of effecting a permanent improvement in the pasture will not again occur for many years.

From the third to the sixth year is likely to be a critical period in the history of the pasture, and the manuring should be on a liberal scale, even if the cost is somewhat high. A light dressing of farmyard manure, if available, would do great good, or failing this, the stock should be liberally fed with oilcake (preferably with decorticated cotton cake), or artificial manure may be applied. A mixture of 2 cwt. superphosphate, 2 cwt. kainit, and ½ cwt. fish meal per acre, costing about 13*s.*, would probably prove useful in the spring of the fourth and sixth seasons, and if the soil were damp, and the herbage were late in growing in spring, an occasional application of 10 to 15 cwt. slaked lime per acre in February would be likely to assist nitrification and the spread of the grasses.

Medick, bird's-foot-trefoil and suckling clover appear to be of much less value than white clover as improvers of soil, and when white clover plants are few (one to a square yard) or are absent, the plan of scattering some seed on the surface, adopted with success at Wendon Lofts, may be tried. Occasionally on a soft surface the seeds may be roughly harrowed in, but the surface of a clay pasture will usually be too hard to yield to the tines of a harrow. By repeated harrowings in wet weather a slight surface tilth was obtained on a clay soil at Cockle Park, but the results did not justify the cost. The Wendon Lofts plots were sown in spring, and the clovers were fortunate in meeting a favourable season, but even in the dry season of 1904 a case of successful sowing has come to the knowledge of the writer. In the South of England it is probable that autumn sowing would usually give better results than spring sowing, but the point has still to be tested. At Wendon Lofts seed was sown at the rate of 12 lbs. per acre, but from the appearance of the crop in 1904 it was evident that 3 lbs. would have been enough. Those who

wish to experiment on sowing clover in this way are recommended to try from 3 to 6 lbs. per acre. The seed of wild white clover was sown at Wendon Lofts, but this is scarce and expensive, and it seems likely that ordinary white clover seed would serve the purpose.

Where Gramineæ are very poorly represented it would probably pay to sow small quantities (3—5 lbs. per acre in all) of such hardy grasses as crested dogstail, hard fescue, and timothy, either with the clover seed, or a year later. It would not be necessary to sow much, for if the grasses got a footing in the pasture they would spread quickly after the soil had been enriched by clovers, and it would not be prudent to spend more than a small sum on the attempt to introduce grasses, for they do not establish themselves so readily as white clover, and are very liable to die off in unfavourable summers.

DISCUSSION OF THE METHOD.

It will have been remarked that the returns from some of the manures used have been unusually high, and, as the method of the experiment is new and has met with some criticism, it will be desirable before concluding to examine it and to discuss its accuracy and limitations.

There are four points in the method to which attention may be directed in this connexion, viz.: (1) the small number of sheep employed; (2) the small size of the grazing areas; (3) the propriety of depasturing by sheep only; (4) the value of live-weight increase as a test of progress.

The number of sheep usually varies from six on the unmanured plot to twelve on the best plots. In some years as few as four animals have been put on an untreated plot. In such small lots there is a danger that the results may be unduly affected by the quality of the individual sheep in the different lots. The writer has carefully considered this question and has compared the increase made by individual sheep on grass in a number of cases, and he does not think that the above cause could have produced any serious errors in the results. As compared for example with sheep on winter diet, sheep on grass make very uniform gains, and if reasonable care is taken in the selection and supervision of the sheep even the smaller lots will not suffer from the influence of the individual.

The second point is one raised by farmers. Some flockmasters contend that it is impracticable to fold sheep on three acres of land

for from 16 to 20 weeks, because the health of the sheep must suffer, and therefore the increase made will bear no relationship to the quality of the pastures. In answer to this it may be pointed out that the number of sheep put on the grass rarely exceeds four animals to the acre, so that the land does not get foul, and further that as a matter of fact the sheep remain perfectly healthy. The casualties at Cockle Park for the first five seasons were but little over 2 per cent., and in almost every case the casualties were caused by the maggot-fly or the "gid" cyst (*Cœnurus cerebralis*), and had no connexion with the system of grazing. On some of the plots sheep did cease growing, but the cessation was due to unsuitable or scanty pasturage, and all the sheep were affected alike; no diseases were set up by a foul condition of the pastures.

The third criticism of the method is raised from the standpoint of the pasture. It is contended that when grass land is depastured by sheep only it does not always get a fair chance, and that much better results would have been obtained from the experimental pastures if a mixed stock of cattle and sheep had been kept.

This objection is a sound one. It may at once be admitted that better results would have been got if a mixed stock had been put on the grass; but it would have been impracticable to have used cattle in the particular cases under discussion, and there would be many difficulties in carrying on the experiments on such a scale as would have admitted of the grazing of both cattle and sheep. The difficulty in grazing with sheep only is that strong-growing grasses cannot be kept down, and when they run to seed the quality of the pasturage deteriorates. The poor pastures in their natural state were easily kept under, but when improved by manuring more or less of the grass was always wasted. The stronger the growth of the grasses the greater was the tendency to waste, and under ordinary farming conditions the results obtained from manures would always have been greater than those shown by the experimental plots. Plots 9 and 10 receiving nitrogenous manures suffered most from this limitation in the method, but the injury done them was small, and under no circumstances could the returns from these plots have been such as would have altered the conclusions stated on p. 131.

The results from some pastures are more affected by grazing difficulties than others, and in the group of stations now under notice Yeldham suffered most. Under the influence of certain of the manures heavy crops of grass were produced during the later months of the season at this station, but the sheep derived no benefit from the

pasturage, and the manures have therefore received no credit for the increased growth.

The fourth objection to the method lies in the use of live-weight increase as a measure of the value of the manures. Live increase does not contain a fixed proportion of mutton. In lean animals the increase is more watery in character than in fat, and the increase made on the worst plots where the sheep remain thin throughout the season is therefore worth less than the increase on the best plots where the animals are in higher condition. An attempt to meet this difficulty has been made by adjusting the numbers of the stock to the quality of the pasture, and on all the improved plots the live increase has approximately the same value; but the sheep on the unmanured land, however few in number, always remain in very lean condition, and the increase they make is worth less per lb. than the increase made by the fatter sheep on the manured land.

The limitations in the experimental method are therefore not of a serious kind. There is a tendency to under-estimate the extent of the improvement due to manuring, but it is much safer to under-estimate than to exaggerate. As between the different plots this method holds the balance very evenly, and month by month there is a close agreement between the appearance of the herbage and the gains made by the sheep. From the detailed reports on the experiments evidence of this close agreement may be obtained, and the following example may be cited.

During the years 1900–02 the writer frequently visited the Cockle Park experiment in company with experienced farmers, and notes were made on the appearance of the pastures. In 1900 Plot 5 was considered slightly inferior to Plot 4, in 1901 the positions were reversed, but in 1902 Plot 4 was again the better. In 1900 Plot 10 was very similar to Plot 9, in 1901 it was better than Plot 9 but not equal to Plot 5. In 1902 Plot 10 contained a little more grass than Plot 5. In each of the seasons Plot 2 was considered very inferior to, and Plot 8 very much better than, any of the four plots already mentioned. The actual increase in pounds per acre made by the sheep was as follows:

		Plot 2.	Plot 4.	Plot 5.	Plot 8.	Plot 9.	Plot 10.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1900	...	60	139	137	159	128	134
1901	...	41	107	115	144	98	100
1902	...	68	146	127	164	120	139

SUMMARY.

1. The results of six experiments in the manuring of poor pastures are described. The experiments were made in the counties of Northumberland, Northampton, Cambridge, Essex, Norfolk, and Hants. The results are given for a period of three years at all stations (except Norfolk, two years), and for two further periods of three and two years at the Northumberland station.

2. In Norfolk on a light soil a potash manure slightly improved the pasture; the other manures had no influence on the yield. At the remaining five stations on heavy soils phosphatic manures produced highly profitable returns. In the first period, the use of other manures was not justified by the results. Where, however, the experiment was continued for eight years, lime proved profitable in the second, and potash in the third period. Under the special conditions of the experiment nitrogenous manures were either injurious or but very slightly increased the yield.

3. From the results given in the tables on pp. 128 and 132, and from frequent examinations of the character and progress of the pastures the following explanation of the effects of the manures is offered: Phosphatic manures stimulate into rapid growth such Leguminosæ as white clover (*Trifolium repens*), suckling clover (*T. minus*), and medick (*Medicago lupulina*), which are almost everywhere present in a starved, undeveloped state on barren pastures. These soon cover the soil and in many ways improve its quality. In the third or fourth year Gramineæ begin to spread rapidly in the improved soil, the Leguminosæ at the same time diminish, and the pasture assumes a mixed character. The presence of lime greatly assists the spread of grasses. For the first few years the available potash of a clay soil appears to supply the needs of the Leguminosæ. After a time, possibly in from four to six years, on ordinary poor pastures, potash manures become necessary. In some cases it is likely that the need for potash may be much longer delayed.

4. Specific directions for the treatment of poor pastures are given. These directions are based on the following considerations:

(1) The greater the development of the Leguminosæ during the first three years the greater will be the ultimate improvement.

(2) The growth of clovers is much hindered by competition with grasses, therefore any treatment likely to stimulate grasses must be avoided for the first two years.

(3) It is impossible to maintain a purely leguminous herbage, clovers will partly (sometimes almost completely) disappear in the course of three or four years; further, a mixed herbage is desirable from the grazier's standpoint. It is desirable therefore to encourage grasses from the third or fourth season onwards, and the treatment should be directed towards establishing a mixed herbage.

(4) In the formation of a mixed herbage manures are necessary, but careful depasturing will usually be of greater importance than manuring.

5. Since it contains both phosphoric acid and lime, basic slag is the most useful manure with which to begin the improvement of poor clay pastures. In the second stage the residues of oilcakes fed on the land are likely to give the best results, but with these other manures may be necessary.

6. Cases of the failure of phosphatic manures on soils are considered, and it is shown that failures may be due to (1) absence of Leguminosæ; (2) absence of conditions suitable for the active growth and full development of Leguminosæ, such as an insufficient supply of moisture, injury to runners and roots through cracking of the surface soil, competition with the grasses of an old turf, or lack of available potash.

CALCIUM CYANAMIDE.

By A. D. HALL, M.A.,

Director of the Rothamsted Experimental Station. (Lawes Agricultural Trust.)

CALCIUM Cyanamide represents the first attempt on a commercial scale to bring atmospheric nitrogen into a state of combination, to manufacture, in fact, an artificial manure containing nitrogen derived from the air. The starting-point for the manufacture is the well-known substance calcium carbide, which is produced by heating in the electric furnace a mixture of chalk and coke or some other form of carbon. The calcium carbide, now so generally employed for generating acetylene for lighting purposes, is almost wholly made where cheap power to produce electricity can be obtained from a waterfall, and the manufacture of calcium cyanamide must naturally take place alongside, so as to secure a cheap supply of carbide. The remaining process is simple enough; the calcium carbide is reduced to a coarse powder, placed in a vessel resembling a gas retort and brought to a temperature approaching white heat, when a current of nitrogen gas is led over it until combination ceases. The result is a compound containing nearly 20 per cent. of nitrogen, crude calcium cyanamide, the formula of which when pure would be represented by $CaCN_2$. The nitrogen required in the manufacture is obtained from the air in the simplest way by passing air through a heated cylinder packed with copper turnings; the oxygen combines with the copper and the nitrogen passes forward into a gasholder until required. The copper is regenerated by passing a current of coal-gas through the heated cylinder. The resulting crude calcium cyanamide is a fine black powder, which decomposes rapidly when heated with water under pressure, and slowly with water at ordinary temperatures, into calcium carbonate and ammonia, in accordance with the equation

$$CaCN_2 + 3H_2O = CaCO_3 + 2NH_3.$$

Cold water and the action of acids extract a substance dicyandiamide $(CN_2H_2)_2$, noteworthy as containing two-thirds of its weight of

nitrogen. This substance is of no service to plants, but appears to have some use in connection with the manufacture of high explosives. From the crude calcium cyanamide it is easy to prepare the cyanides of sodium or potassium, and sodium cyanide manufactured in this fashion is now on the market.

The nitrogen in the crude calcium cyanamide is best determined by digesting it with strong sulphuric acid by the usual Kjeldahl's method.

The manufacture of crude calcium cyanamide has not yet been taken up on a large scale, a model plant is in operation in Berlin capable of turning out quantities of about 1 ton per diem, and arrangements are being made with other firms to develop the process commercially.

Through the kindness of the Cyanid Gesellschaft of Berlin the Rothamsted Experimental Station was furnished with 50 kilos of the material, containing 19·7 per cent. of nitrogen, in the spring of 1904. It was then too late to use it for any cereal crop, since it cannot be employed as a top dressing, but arrangements were made for experiments with roots.

As a manure it should be applied to the soil some little time before the seed is sown and should be lightly ploughed in, lest any loss of ammonia take place. It cannot well be mixed with other manures; with superphosphate, for example, the reaction is somewhat intense and the whole mass becomes very hot. It was decided to compare its action with that of an equivalent amount of nitrogen in the shape of sulphate of ammonia, superphosphate and sulphate of potash being equally supplied to both. The Rothamsted soil is a somewhat heavy stony loam, almost a clay in the subsoil; the surface soil contains a fair supply (from 1 to 3 per cent.) of carbonate of lime, so that sulphate of ammonia is always an effective source of nitrogen.

The following table shows the comparative results obtained with Mangels, Swedes, and Mustard respectively.

It was noted in each trial that the plot receiving sulphate of ammonia made the better start and was distinctly more advanced, as long as the roots were small. In the trial with swedes the differences were very pronounced until the end; this was a poor piece of land, very much out of condition, and though a very regular plant was obtained and a good start made, the roots grew but little during the autumn, owing to the dryness of the season. In the trial with mangels, the plants receiving sulphate of ammonia had the better appearance throughout, the leaves were of a darker green and seemed more luxuriant. Owing to insect attacks, however, both plots lost rather

CALCIUM CYANAMIDE *versus* SULPHATE OF AMMONIA, AT ROTHAMSTED, SEASON 1904.

	Produce per acre				
	Mangels		Swedes		Mustard
	Roots	Leaves	Roots	Leaves	
	Tons	Tons	Tons	Tons	Tons
1. Sulphate of Ammonia	19·71	2·95	13·40	1·31	4·37
2. Calcium Cyanamide...	20·25	2·54	9·98	0·95	4·16

Manuring—For *Mangels*—200 lb. Superphosphate (37 %), 200 lb. Sulphate of Potash, and 300 lb. Sulphate of Ammonia or 315 lb. Calcium Cyanamide, per acre.
For *Swedes*—4 cwt. Superphosphate (37 %), 1 cwt. Sulphate of Potash, and 200 lbs. Sulphate of Ammonia or 210 lb. Calcium Cyanamide, per acre.
For *Mustard*—4 cwt. Superphosphate (37 %), 1 cwt. Sulphate of Potash, and 200 lb. Sulphate of Ammonia or 210 lb. Calcium Cyanamide, per acre.

Mangels—Seed sown, May 7. Crop harvested, Nov. 4. Plants on (1) 76 %, and on (2) 77·3 % of possible.
Swedes—Seed sown, May 25. Crop harvested, Nov. 15. Perfect plant.
Mustard—Seed sown, July 27. Cut, Sept. 21.

a high proportion of plants, so much so that I should not attach much weight to the result. In the trial with mustard the cyanamide plot was the slower to start, but when in full flower no difference could be seen between the two plots.

Speaking generally the trials do not warrant any definite conclusion as to which is the better source of nitrogen, calcium cyanamide or sulphate of ammonia; two of the three experiments would make the cyanamide as good a source of nitrogen as sulphate of ammonia, but as has already been stated one of these experiments may be considerably in error. The third trial, a very uniform and even experiment, which looked trustworthy, was decidedly in favour of the sulphate of ammonia, but on the other hand on this plot the cyanamide by mistake had been mixed with the other manures and burnt earth before sowing. Again the stoppage of growth through the drought did not give the cyanamide as good a chance, if we may assume it requires time and plenty of moisture to set free all the ammonia.

There can be little doubt however that calcium cyanamide is an effective nitrogenous manure, though more extended experiments are necessary to decide whether the unit of nitrogen is worth more or less in its case than in sulphate of ammonia.